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The Cost of Clean Water and Its Economic Impact Volume IV. Projected Wastewater Treatment Costs in the Organic Chemicals Industry

Cyrus Wm. Rice and Company, Pittsburgh, Pennsylvania

Prepared for

Federal Water Pollution Control Administration, Washington, D.C.

10 Jan 69

[redacted]

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THE COST OF CLEAN WATER AND ITS ECONOMIC IMPACT

VOLUME IV

PROJECTED WASTEWATER TREATMENT COSTS in the ORGANIC CHEMICALS INDUSTRY

A study conducted by:

Cyrus Wm. Rice and Company
Pittsburgh, Pennsylvania

In cooperation with

W. Wesley Eckenfelder, Jr. and Associates
Austin, Texas

Roy F. Weston, Inc.
West Chester, Pennsylvania

Resource Engineering Associates, Inc.
Stamford, Connecticut

Prepared under contract with the
Federal Water Pollution Control Administration
U.S. Dept. of the Interior

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JAN 1 0 1969

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I. SUMMARY

This report presents an estimate of the costs that would be incurred by the organic chemicals industry in attaining various levels of pollution abatement over a five-year period and gives a generalized methodology by which similar continuing estimates can be made for other water-using industries. Cost estimates have been based upon published data, general data derived from information in the files of the Contractors on industrial waste treatment methods and costs, and specific data from 53 organic chemicals plants; the latter specific data were used to verify the applicability and accuracy of the former and also to develop and test the generalized methodology.

It should be emphasized that the total costs given in this report are for the construction and operation of waste treatment facilities for the industry as a whole and cannot be used to determine costs for individual plants. Organic chemicals plants vary greatly in size, level of technology, product mix, etc., and a "typical" or "average" plant exists only in a statistical sense. The costs given are, in general, for waste treatment facilities only, i.e., for "battery limit" industrial waste treatment plants. The costs entailed in process changes, disruption of plant operations, sewer segregation, monitoring and reporting waste treatment efficiency, etc., particularly in older plants, are not included. Such costs are practically impossible to estimate in the aggregate and may add 40 percent or more to the installed costs of facilities. Total costs for particular plants can only be estimated by detailed engineering studies; the unit costs in this report should be of value to engineers in making such estimates.

INDUSTRY PROJECTIONS

The following data are estimated for the organic chemicals industry for the years 1969 and 1973, based upon the methods and assumptions detailed in the report.

	1969	1973
Number of Large Plants	245	276
Production in Large Plants (10^9#)	128.8	191.5
Total Industry Production (10^9#)	135.6	201.6
Waste Water Volumes:		
Large Plants (10^9 gpy)	287	323
Large Plants (gpd/ton/yr)	12.2	9.23
Municipal Discharges (10^9 gpy)	94.9	141

The data indicate that the average large plant can be expected to treat 3.2 mgd of wastewater during the five-year period 1969-1973. The capital costs for such an average plant are given below versus the level of treatment attained, in 1968 dollars.

Level	Removal Critical Pollutants			$/1000 gpd	Cost (3.2 mgd)
	BOD	COD	SS		
1	Removal of Gross Pollutants			147	$ 470,400
2	10%	10%	65%	176	563,200
3	83%	13%	71%	250	800,000
4	98%	30%	89%	700	2,240,000
5	99%	33%	99%	751	2,403,200
6	100%	100%	100%	1648	5,273,600

On the basis of the above costs in the average large plant, the estimated numbers of large plants, the total estimated discharges to municipal sewers, and the assumption that the capital costs associated with the latter disposal means are those entailed in Level 1 treatment, capital costs are estimated as follow for the entire industry in terms of current dollars, using the ENR Construction Cost Index to adjust 1968 prices.

	Industry Capital Costs (Millions of Dollars)				
Treatment Level	1969	1970	1971	1972	1973
1	158.9	172.6	188.3	204.8	222.6
2	182.5	197.8	215.1	233.4	253.2
3	242.6	261.8	283.6	306.5	331.2
4	608.1	561.2	699.9	751.1	805.3
5	649.6	695.3	747.1	801.6	859.1
6	1378.1	1471.4	1576.9	1687.7	1804.2

Estimated operating costs in the average large plant are given below versus level of treatment in 1968 dollars. These costs are based upon data obtained from the sample plants and from published operating cost data.

Level	Removal Critical Pollutants			$/yr/100 gpd	$/yr (3.2 mgd)
	BOD	COD	SS		
1	Removal of Gross Pollutants			7	22,400
2	10%	10%	65%	8.5	27,200
3	83%	13%	71%	13	41,600
4	98%	30%	89%	105	336,000
5	99%	33%	99%	120	384,000
6	100%	100%	100%	350	1,120,000

Assuming that the operating costs associated with the discharge of industrial wastes to municipal sewers are 10 cents per 1000 gpd, the total operating costs for the industry are given below in current dollars, using the ENR Construction Cost Index to adjust 1968 prices.

	Industry Operating Costs (Millions of Dollars)				
Treatment Level	1969	1970	1971	1972	1973
1	15.5	17.3	19.5	21.9	24.4
2	16.8	18.7	20.9	23.4	25.9
3	20.4	22.5	25.0	27.8	30.7
4	95.1	102.1	110.2	119.4	128.3
5	107.3	115.1	124.0	134.3	144.2
6	294.1	314.1	356.8	363.2	388.2

THE ORGANIC CHEMICALS INDUSTRY

The important products of the organic chemicals industry are miscellaneous cyclic and acyclic organic chemicals and chemical products, flavor and perfume materials, rubber-processing chemicals, plasticizers, pesticides, and other synthetic organic chemicals. Of total shipments in 1967, 75 percent were miscellaneous acyclic chemicals, a large number of which are generally designated as petrochemicals. The expansion of the petroleum industry into chemical production is of particular significance insofar as the growth and complexity of the organic chemicals industry is concerned.

Total sales in the organic chemicals industry are estimated to be 11.9 billion dollars in 1969 and 15.6 billion dollars in 1973. Production is estimated at 135.6 billion pounds in 1969, increasing to 201.6 billion pounds in 1973. Growth in the industry is not expected to be uniform either among the various segments of the industry or among the various geographical areas in which the industry operates.

Organic chemicals industry pollutants originate from the incomplete removal of principal products or raw materials from reactions, in the production of non-recoverable or useless by-products, from equipment cleaning operations, and from such water uses as cooling and steam production. Wastewater generation in the industry per unit of product varies so widely that an average value has little meaning except in a statistical sense; wastewater generation varies from less than 100 gallons per ton of product to more than 100,000 gallons per ton of product. The principal contaminants in the industry's wastewaters are BOD, COD, oil, suspended solids, acidity, heavy metals, color, taste-and-odor-producing compounds, and residual organic products and by-products.

The production of organic chemicals results in many types of contaminated wastewaters, and the treatment methods employed cover the range of known practical techniques. In-plant control is the first step in instituting treatment practices. Such controls include the salvage of unreacted chemicals, recovery of by-products, multiple reuse of water, good housekeeping techniques to reduce leaks and spills, and changes in processing methods. These controls can result in reducing the concentrations of almost all potential pollutants and can, most importantly, reduce the volumes of wastewaters requiring treatment. Physical treatment methods such as sedimentation or flotation are used primarily to remove coarse suspended matter and floating oils and scums. Filtration is used as a form of tertiary treatment for reuse or as a pretreatment for deep-well injection. Chemical treatment is used primarily as a pretreatment prior to sedimentation, filtration, or biological treatment. Biological treatment is most widely used in the industry due to the nature of the wastes, that is, their general susceptibility to biodegradation as evidenced by relatively high BOD values.

Joint industrial-municipal treatment has proved to be very effective in treating organic chemical wastewaters, particularly for smaller chemical plants located near large municipal treatment systems. Treatment costs play an important role in governing the expansion of joint treatment participation. Rates established by municipalities vary extremely. Where the municipal system is small and additional contributors would overload the treatment plant, the high rates are imposed to discourage industrial contributors.

The chemical industry has generally found that in-plant, separate treatment has economic advantages, particularly when significant quantities of contaminated wastewater are involved. No significant percentage increase is expected in the amount of organic chemical wastewaters that will be treated in joint systems in the near future. On the basis of an annual production of about 71 billion pounds by the organic chemicals industry in 1963, municipal discharges might be expected to be about 1400 gallons per ton of production for the industry as a whole.

DATA ACQUISITION AND METHODOLOGY

Data from 53 organic chemicals plants were obtained and formatted according to the Industrial Waste Treatment Practices Data Form, which was developed in the course of this study and is described in the report. This form may be used for the acquisition of data upon which the cost-effectiveness of industrial waste treatment practices can be determined in general. Although the form has utility in tabulating data for a single plant or firm, the prime purpose is to format data for analysis in terms of general industry practices. Data formatted in this system can be retrieved according to selected parameters, and can be readily sorted and printed out according to selected parameters, and can be readily analyzed and correlated by machine computation.

The data obtained are given in some detail in the report in terms of bar graphs and various calculated parameters relating wastewater volumes, plant production, and costs. It is of particular significance that the distributions of wastewater volume and annual production are markedly skewed in opposite directions and, although most of the plants surveyed were judged to be medium or large in terms of production, employment was relatively low in most cases. The level of technology in the surveyed plants was generally judged to be average or advanced, although the median age of the plants was 18 years. The explanation of such an apparent anomaly lies in the relatively short lives of chemical processes and equipment; replacement equipment and new processes installed in even the older plants tend to be of modern design.

The most frequently reported basis for action decisions by plants was that the legal requirement existed, although legal actions and public opinion cases were both mentioned. The particular treatment decision was based upon least total cost most often; least total cost generally means the least capital and operating costs over an arbitrary time period and is not evaluated in any sophisticated sense such as would be involved in considering savings in water use, etc.

The costs of unit wastewater treatment methods were developed and are presented in the report as a series of mathematical models and cost function graphs. These data were then used to calculate capital costs of waste treatment facilities versus degree of pollutant removals attainable for 20 typical plants. Both the unit cost data and the design criteria for the example plants were checked for reliability and likelihood on the basis of the 53-plant data.

Analysis of the available data indicated that estimates of industry-wide costs in the organic chemicals industry would best be made on the basis of estimated costs per plant and estimated numbers of plants. Alternative calculations could have been made on the basis of estimated costs per unit volume of wastewater and estimated wastewater volumes. Cost estimates are based, additionally, upon the assumption that wastewater generation per unit of production will decrease as wastewater treatment facilities are installed and that the costs involved in discharging to municipal sewers are those of in-plant removal of gross pollutants plus a surcharge of 10 cents per 1000 gpd.

METHODOLOGY FOR WASTEWATER TREATMENT COSTS DETERMINATION

The methods which have been developed and used in this study of the organic chemicals industry can be utilized to determine wastewater treatment costs for other industries. The methodology is intended to be used in establishing and projecting costs for an industry or for groups of industries, rather than for individual plants. Costs estimates for individual plants are readily calculable by conventional engineering techniques to almost any degree of precision desired, depending upon the effort to be expended and the intended uses of the information. Costs for an industry could, of course, be determined precisely by calculating the costs of treatment facilities for each individual plant in an industry and totaling these costs. Alternatives to this obviously impractical method are to estimate the number of plants involved and multiply by the "average" cost per plant or to estimate the volume of wastewater involved and multiply by the "average" cost per unit volume of wastewater; such alternative methods are practical and offer a degree of accuracy sufficient for purposes of industry-wide planning and economic impact studies. The suggested methods for determining the total costs to an industry of attaining specified degrees of wastewater effluent quality over a time period are outlined in the report, as a series of steps as follows:

1. Characterization of the Industry
2. Projection of Industry Growth
3. Characterization of Wastewaters
4. Wastewater Treatment Methods Determinations
5. Sample Plant Data Acquisition
6. Sample Data Analysis
7. Unit Wastewater Treatment Methods Costing
8. Determination of Cost vs. Effluent Quality Relationships
9. Projection of Industry Wastewater Generation
10. Project of Industry Costs

Guidelines have been established for the use of this methodology and its use has been demonstrated in the organic chemicals industry. Each industry has its own peculiar characteristics and care must be taken that these are recognized in applying any general schemes; for example, in the present study production-related parameters were shown to be of prime importance, a reliable estimate of numbers of plants was available, and the "average" plant costs were closely estimated by two alternative techniques. In another industry the most likely set of data might well be different.

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II. INTRODUCTION

This study was performed pursuant to Contract No. 14-12-435, with the Federal Water Pollution Control Administration, Department of the Interior, and is a part of the National Requirements and Cost Estimate Study required by the Federal Water Pollution Control Act as amended.

The objectives of this study have been to develop estimates of the costs to the organic chemicals industry of attaining, in a five-year period, (a) State water quality standards and (b) specific levels of removal of significant pollutants; and further to develop a generalized methodology by which similar continuing estimates can be made for other water-using industries.

These objectives have been accomplished by using data from 53 organic chemicals plants to estimate and predict present and future treatment methods and costs in the industry and to develop and test the generalized methodology.

The chemical industry has already expended much money and effort in wastewater treatment facilities and in seeking new solutions in pollution control. These efforts, however, have not been uniformly distributed among either the individual plants or among the various geographical areas in which chemical plants are operated.

The effectiveness of installed wastewater treatment facilities has also not been uniform; some plants have wholly adequate facilities to meet present and projected effluent quality requirements, but many other plants have only marginal or inadequate facilities.

The information given in this report is not intended to reflect the cost or wasteload situation for any particular plant. However, a generalized framework has been provided for analyzing waste treatment practices and it is hoped that the data given will be useful in industry's efforts to find and implement the most efficient ways to reduce wastewaters and resulting stream pollution.

The comments and suggestions received from members of the Water Resources Committee of the Manufacturing Chemists' Association are gratefully acknowledged.

III. THE ORGANIC CHEMICALS INDUSTRY

The organic chemicals industry is not readily definable in terms of the Standard Industrial Classification (SIC) numbers. Present classifications, based upon 1967 revisions, include SIC 2815 [Cyclic Intermediates, Dyes, Organic Pigments (lakes and toners), and Cyclic (coal tar) crudes]; SIC 2818 (Organic Chemicals, not elsewhere classified); portions of SIC 2813 (industrial gases); portions of SIC 2879 (agricultural chemicals not elsewhere classified); and portions of SIC 2871 (fertilizers). On the basis of the older SIC numbers the industry included portions of SIC 2811 (fertilizers) and included SIC 2814 [Cyclic (coal tar) crudes]. For the purposes of this study, organic gases only were included from SIC 2813 and ammonia and urea only from the Fertilizer Industry (SIC 2879 and 2871, or the revised SIC 2811).

The important products of the organic chemicals industry are miscellaneous cyclic and acyclic organic chemicals and chemical products, flavor and perfume materials, rubber-processing chemicals, plasticizers, pesticides, and other synthetic organic chemicals. The organic chemicals industry ordinarily includes production of monomers, but does not include production of polymers or plastics and synthetic fibers. Of total shipments in 1967, 75 percent were miscellaneous acyclic chemicals, a large number of which are generally designated as petrochemicals. The expansion of the petroleum industry into chemical production is of particular significance. Detailed descriptions of the principal products of the petrochemical industry are contained in Appendix C.

The overall output of industrial chemicals depends primarily on total economic activity rather than on any specific segments of the economy. Changes in consumer preferences or redistributions of income and spending such as tax increases with increased defense spending affect product mixes, but do not significantly affect the total output of the industry. There is some price competition among industrial chemicals which are possible substitutes; the demand is primarily derived from the demand for other goods using industrial chemicals in their manufacture. Non-price competition, particularly in the development of new or improved chemicals, is the dominant form of competition in the industry.

Raw materials for industrial chemicals have been readily available and at rather stable prices. Future raw materials shortages may develop in the organic chemicals industry as petroleum fractions are diverted to produce higher value products such as fuel oil and gasoline. Industrial chemical industries are generally capital-intensive operations with high productivity ($75,000 annual output per production worker), high wages, a low labor turnover, and a demand for skilled labor. Most of the large plants operate continuous processes and must operate at a high percentage of capacity to maintain acceptable efficiency levels and profitability. Smaller plants generally operate batch processes and produce low-volume, high-cost, specialized chemicals. Financial ratios for the Industrial Chemicals Industry are shown in Table I.

TABLE I

FINANCIAL RATIOS FOR THE INDUSTRIAL CHEMICALS INDUSTRY

Ratio	1963	1964	1965	1966	1967(1)
Profits after taxes/sales (%)	7.5	7.9	7.9	7.8	7.0
Profits after taxes/net worth (%)	12.9	14.3	14.7	14.7	-
Capital Expenditures/gross plant (%)	6.7	7.3	8.6	8.7	-
Depreciation/gross plant (%)	6.1	5.8	5.8	5.8	-
Depreciation/sales (%)	4.5	4.4	4.4	4.4	-
Sales/total assets	1.1	1.1	1.1	1.1	-

SOURCE: U. S. Industrial Outlook 1968, U. S. Dept. of Commerce
(1) First half

By comparison, profits after taxes as percentages of sales for all manufacturing industries were 5.6 in 1966 and 5.0 in 1967. Estimated values of shipments in the Industrial Chemicals Industry for 1968 are shown in Table II.

TABLE II

VALUES OF SHIPMENTS IN THE INDUSTRIAL CHEMICALS INDUSTRY - 1968

Industry Group	SIC	Value of Shipments ($\$10^6$)
Alkalies and Chlorine	2812	880
Industrial Gases	2813	620
Intermediates, Dyes, Crudes	2815	1,770
Inorganic Pigments	2816	630
Organic Chemicals, n.e.c.	2818	7,700
Inorganic Chemicals, n.e.c.	2819	4,300
Total	281	15,900

SOURCE: U. S. Industrial Outlook 1968, U. S. Dept. of Commerce

Organic chemicals thus constitute about 60% of the entire Industrial Chemicals Group in terms of value of shipments. The Industrial Chemicals Industry in 1966 had a total value added of $7,700 million dollars and shipments valued at $13,857 million dollars. The price index for the industry in 1966 was 95.7 on the basis of 1957-59 = 100.

Several factors which characterize the organic chemicals industry, particularly the petrochemical industry, bear significant relationships to waste management problems in the industry:

(a) The industry is characterized by a rapid growth pattern. It is anticipated that the petrochemical industry will expand (on a volume basis) at the annual rate of 8-12%. Pollution control problems will, of course, be increased in some relation to increased production capacity.

(b) The industry is characterized by low capital investment per dollar of sales together with a low labor rate per dollar of sales; additional investments and labor expenditures for pollution control thus tend to appear relatively high when expressed in terms of sales dollars and compared with expenditures for production facilities.

(c) Rapid technological obsolesence is a constant factor in the industry. This is in part a reflection of the relative immaturity of the industry as well as the large number of chemical reaction combinations available in preparative organic chemistry. Wastewater treatment facilities must, therefore, be relatively flexible to accommodate frequent changes in production methods.

(d) The overall price index of chemicals, in contrast with the general experience of American industry, has fallen 3-6% in the recent past. Expenditures for pollution control are of greater significance than in some other industries where increasing prices can absorb increased costs.

(e) The industry has considerable spare production capacity because of the interchangeability of processing units, the availability, during periods of materials shortages, of obsolete or retired units, and because of the various alternative sources of many basic chemicals. Wastewater treatment facilities must accommodate all of the likely production methods and be sized on the basis of plant capacities.

(f) The petrochemical industry is characterized by complicated interrelationships between processes wherein (see Figure 1-3) petrochemicals travel through a variety of stages (usually at least 2-3) before arriving at a point where the product has consumer identity. For example

(1) Naphtha is thermally treated to produce ethylene
(2) Ethylene is reacted with chlorine to form ethylene dichloride
(3) Ethylene dichloride is cracked to produce vinyl chloride
(4) Vinyl chloride is polymerized to produce polyvinylchloride

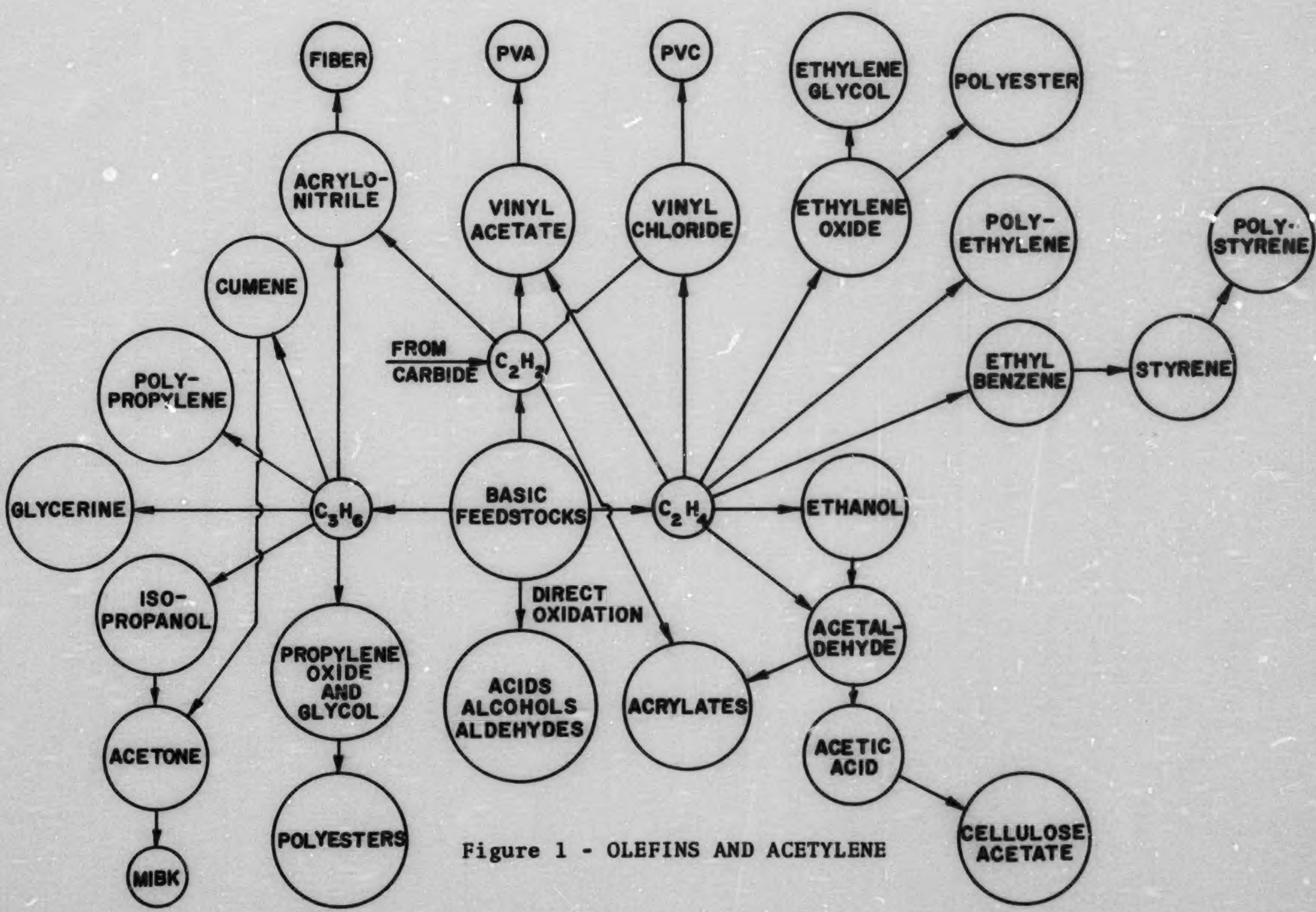

FIBER
PVA
PVC
ETHYLENE GLYCOL
POLYESTER
ACRYLO-NITRILE
VINYL ACETATE
VINYL CHLORIDE
ETHYLENE OXIDE
POLY-ETHYLENE
POLY-STYRENE
CUMENE
FROM CARBIDE
C_2H_2
ETHYL BENZENE
STYRENE
POLY-PROPYLENE
GLYCERINE
C_3H_6
BASIC FEEDSTOCKS
C_2H_4
ETHANOL
DIRECT OXIDATION
ISO-PROPANOL
PROPYLENE OXIDE AND GLYCOL
ACETAL-DEHYDE
ACIDS ALCOHOLS ALDEHYDES
ACRYLATES
ACETONE
ACETIC ACID
POLYESTERS
MIBK
CELLULOSE ACETATE

Figure 1 - OLEFINS AND ACETYLENE

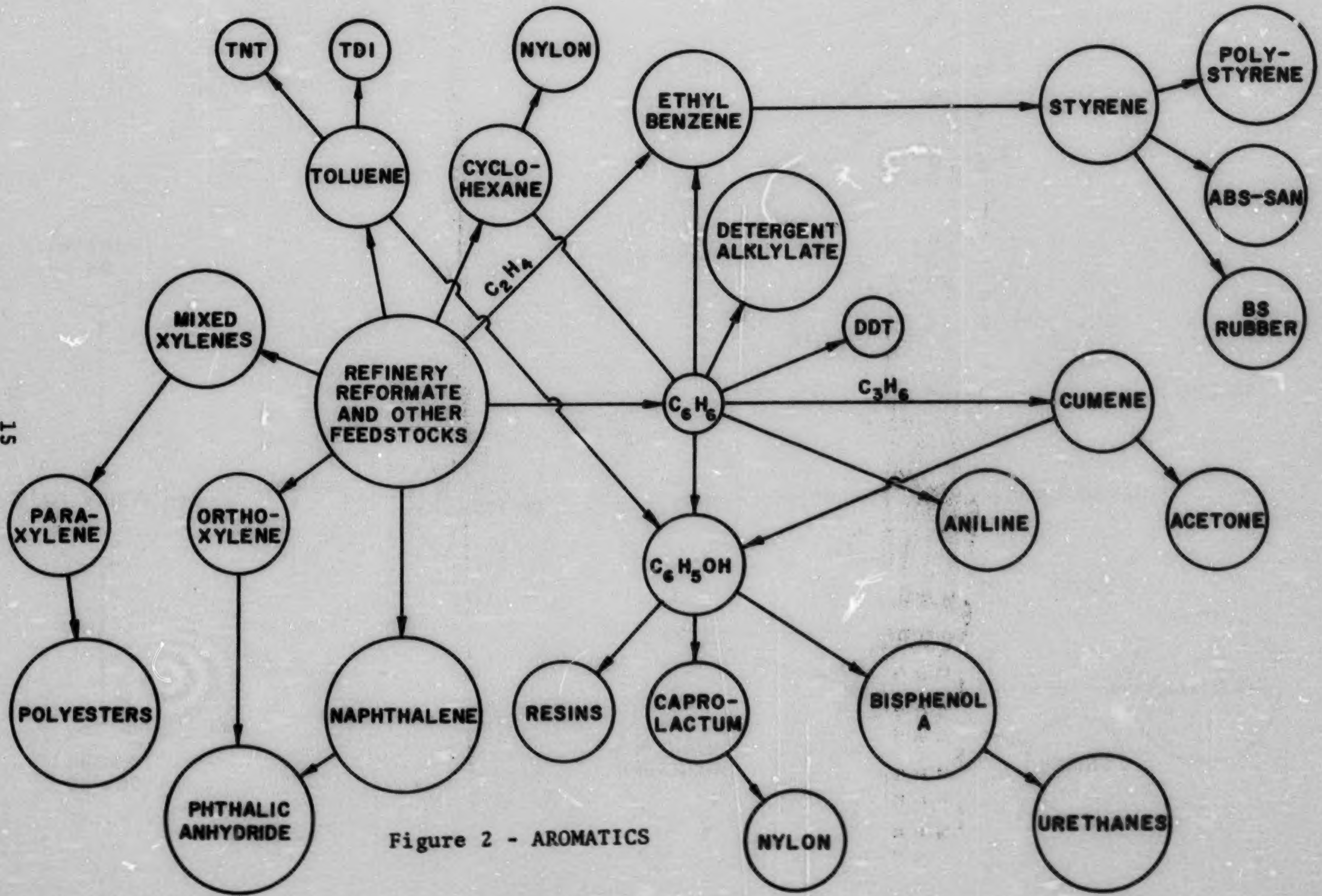

TNT
TDI
NYLON
TOLUENE
CYCLO-HEXANE
ETHYL BENZENE
STYRENE
POLY-STYRENE
ABS-SAN
BS RUBBER
DETERGENT ALKLYLATE
DDT
C_2H_4
MIXED XYLENES
REFINERY REFORMATE AND OTHER FEEDSTOCKS
C_6H_6
C_3H_6
CUMENE
ACETONE
ANILINE
PARA-XYLENE
ORTHO-XYLENE
C_6H_5OH
POLYESTERS
NAPHTHALENE
PHTHALIC ANHYDRIDE
RESINS
CAPRO-LACTUM
BISPHENOL A
NYLON
URETHANES

Figure 2 - AROMATICS

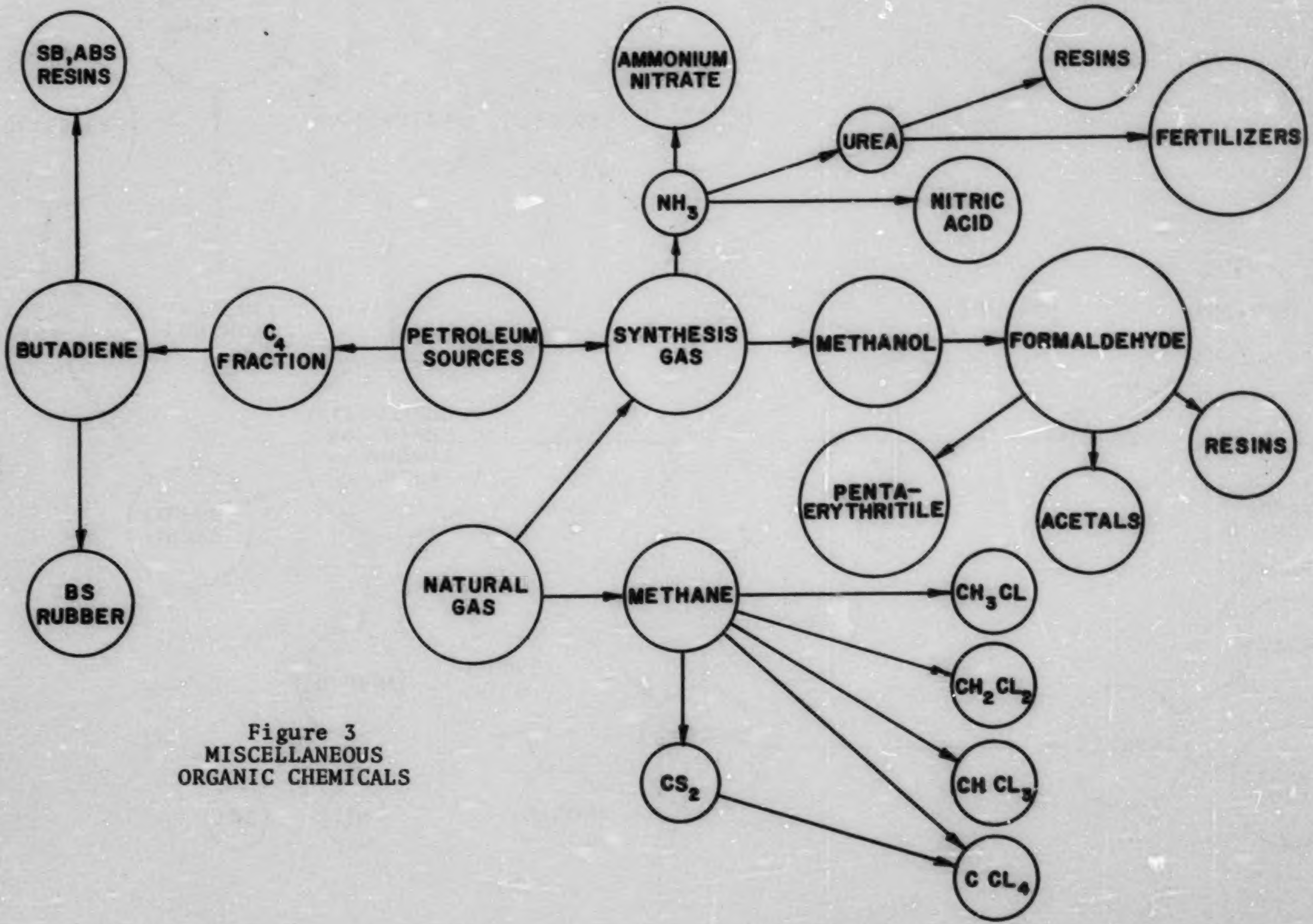
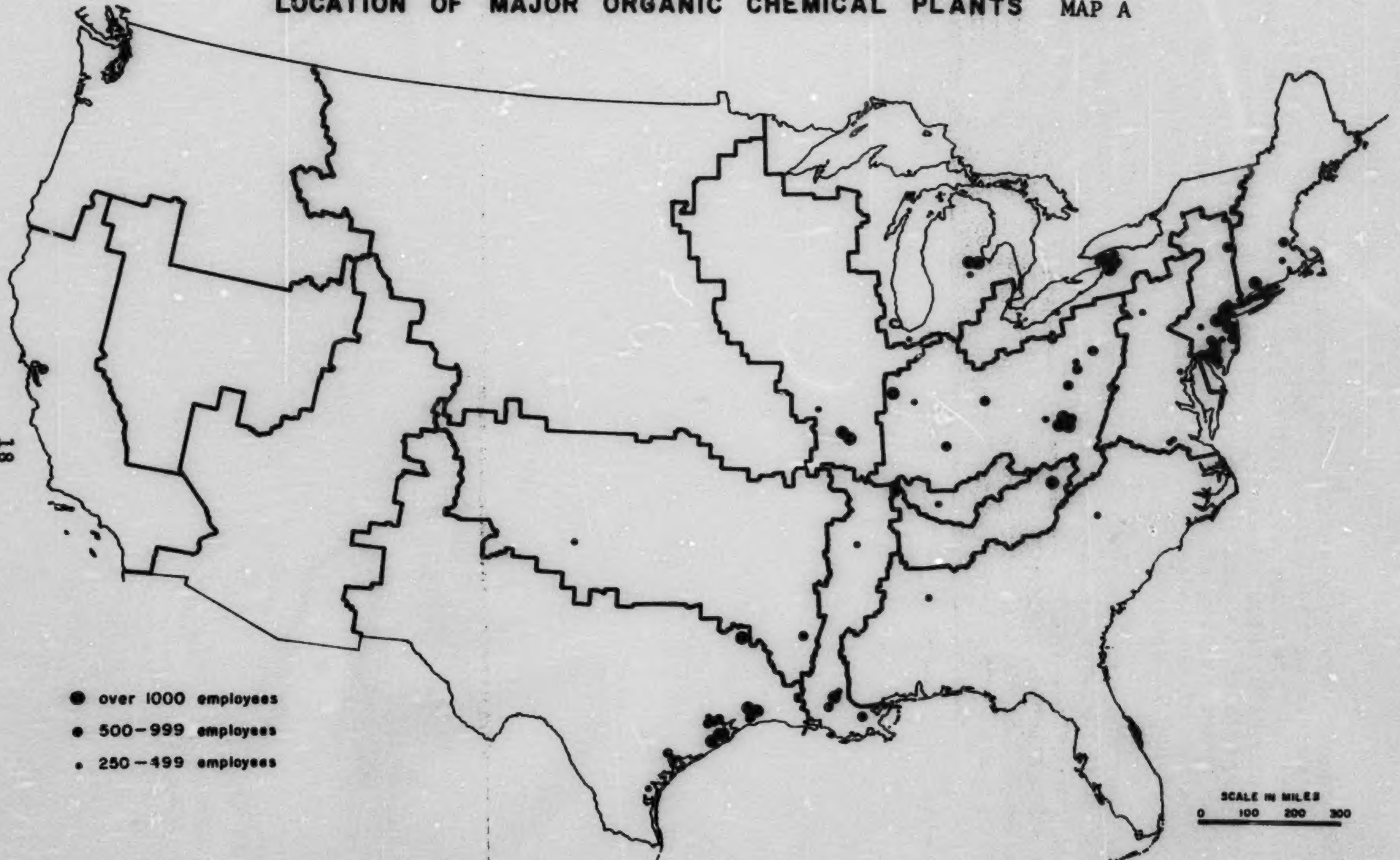

SB,ABS RESINS
BUTADIENE
BS RUBBER
C4 FRACTION
PETROLEUM SOURCES
NATURAL GAS
AMMONIUM NITRATE
NH3
SYNTHESIS GAS
METHANE
CS2
UREA
NITRIC ACID
RESINS
FERTILIZERS
METHANOL
FORMALDEHYDE
PENTA-ERYTHRITILE
ACETALS
RESINS
CH3CL
CH2CL2
CH CL3
C CL4

Figure 3
MISCELLANEOUS
ORGANIC CHEMICALS

The organic chemicals industry is confusing to one not well versed in the nature of the industry. This is due to the number of products and processes utilized in the industry and at any particular production site. However, there exist a limited number of processes which account for a significant portion of the industry and an understanding of these processes is important in any evaluation of the industry. The processes are described in detail, by product, in Appendix C.

The geographical distribution of major organic chemical plants in the United States is shown in Map A.

LOCATION OF MAJOR ORGANIC CHEMICAL PLANTS MAP A


● over 1000 employees
● 500-999 employees
• 250-499 employees
SCALE IN MILES
0 100 200 300

IV. PROJECTED INDUSTRY GROWTH

Projected growth in the organic chemicals industry, for the purpose of the present study, is best expressed in terms of production based upon the tonnage of chemicals produced. Growth estimates have been obtained from Chemical and Engineering News, a publication of the American Chemical Society. The data are obtained from a sophisticated analysis which incorporates estimates of overall employment, rate of growth of the economy, etc. as well as specific characteristics of the industry and marketability prospects for its products. These data are considered to be the most reliable available.

TABLE III

PROJECTED PRODUCTION AND SALES OF ORGANIC CHEMICALS

Year	Sales 10^9 Dollars	Production 10^9 Pounds	Sales 10^9 Pounds
1964	8.46	78.7	42.8
1965	9.0	88.9	46.8
1966	9.9	100.6	52.7
1967	10.5	111.7	56.6
1968	11.2	122.4	61.6
1969	11.9	135.6	67.1
1970	12.7	150.4	73.2
1971	13.7	166.9	79.9
1972	14.6	183.5	86.9
1973	15.6	201.6	94.3

SOURCE: INDUSTRIAL AND ENGINEERING NEWS, private communication

The above data are applicable to the total organic chemicals industry. Rates of growth in various segments of the industry vary considerably, as do the rates of growth by geographical regions. Expected rates of growth over the next decade according to industry segments and geographical distribution are given in tables IV and V.

TABLE IV

PROJECTED GROWTH RATES IN VARIOUS INDUSTRY SEGMENTS THRU 1975

Industry Segment	Growth Rate (% per year)
Urea and Ammonia	9
Petrochemicals	9
Industrial Gases	5
Cyclic Intermediates, etc.	6
Misc. Organic Chemicals	10

SOURCE: REA Projections

These growth patterns are on a volume of production basis and assume a real growth in the Gross National Product of 3.5% per year. Growth in the petrochemicals industry will be sparked by increased demands for fibers, coatings, plastics, and elastomers. The growth in cyclic intermediates is expected to be due primarily to increased production of ethylbenzene, styrene, and phenol; high growth rates are not expected in dyes and coal-based materials.

TABLE V

INDUSTRY GROWTH RATES BY GEOGRAPHICAL AREAS THRU 1975

Area	Growth Rate (% per year)
Northeast and Middle Atlantic	5
Southeast	10
Puerto Rico and Virgin Islands	10
Gulf Coast	15
North Central States	5
Mid South	5
Pacific Coast and Alaska	25

SOURCE: REA Projections

These growth rates reflect the general tendency for the petrochemicals industry to gravitate toward the petroleum production areas such as the Gulf Coast. Growth in the Southeast reflects growth of the fiber industry as does that in Puerto Rico and the Virgin Islands. Growth on the Pacific Coast reflects the large petroleum discoveries in Alaska.

V. WASTEWATER CHARACTERISTICS

Wastewaters from organic chemicals processing consist of contaminated and of relatively clean effluent streams. In general, the contaminated wastewaters are those which are used in direct contact with products or by-products in reactions, separation processes, vessel cleanouts, etc. The cleaner wastewaters are those used for indirect heat exchange, general washing, etc.

Contaminated Wastewaters

The sources of contaminated wastewaters from petrochemical operations are three-fold. First, wastes containing a principal raw material or product arise during the stripping of the product from a solution. Incomplete removal is a fundamental requirement of any equilibrium process. However, use of more expensive or additional separation equipment may result in reduction of effluents. By-products produced during reactions constitute a second source of wastewaters. Many petrochemical reactions take place under extreme conditions where the vagaries of organic chemistry result in the production of chemicals other than those specifically desired. Often markets cannot be found for these chemicals or they cannot be reasonably recovered and are discarded to the waste stream. New production methods are directed toward increases in yields, and reductions in by-products; accordingly new technology often results in a decrease in this source of waste. Spills, slab washdowns, and vessel cleanouts comprise a third category of effluents and these are generally not controllable by means of process modifications; changes in catalyst concentrations and increases in yields, however, reduce the amount of pollutants from this source and result in some changes in the character of the waste. Some typical contaminated wastewaters associated with general processing are shown in Table VI.

It is difficult to pinpoint wastewater characteristics and quantities according to the primary organic chemical industry, but Table VII presents a partial list of the characteristics associated with specific chemical wastewaters. Dividing the industry into six major product groupings, examples are given for each group: flow is given in terms of volume of wastewater generated per ton of product produced, while characteristics are given in concentrations, mg/l. All values are expressed in terms of approximate ranges. The characteristics given are for plants producing the indicated products and are not necessarily additive in cases where one product shown is produced from another.

Because of the limited data available, the numerous alternative processes for producing the same product, and the variabilities resulting from multi-product facilities, no attempt has been made to define the production or technology levels of the total

TABLE VI

TYPICAL PROCESS GENERATION OF CONTAMINATED WASTEWATERS

Operation	Sources	Typical Pollutants
Process units	Overhead water from distillation, cracking, coking, etc.	Low molecular weight hydrocarbons, coke, gums, organic acid, soaps, salts, phenols and phenolates, cyanides ammonia
	Alkylation and polymerization processes	Acid sludges, spent acids, caustics, oil, bauxite and catalyst fines, corrosion products, hydrogen sulfide
	Hydrodesulfurization and reforming processes	Hydrogen sulfide and miscellaneous gases (hydrogen) coke, gums, catalyst fines
Specific Syntheses	Specific process for specific compound	Acrylonitrile, polyacrylonitrile, acrylic acid acrolein, acetaldehyde, acetonitrile, hydrogen cyanide, etc.
Specific treating operations	Sweetening, stripping, filtering	Hydrogen sulfide, mercaptans, amine, sulfonates, acids, bases, miscellaneous nitrogen and sulfur compounds, ammonia, cyanides, furfural inorganic salts and oxides suspended solids

plant or individual processing equipment. Other variations in characteristics and the quantity of the wastewater flow resulting from recirculation, reuse, and by-product recovery capabilities can significantly alter these factors, even in plants producing the same products and having similar capacities. Where significant amounts of heavy metals or other substances are associated with the wastewaters, these have been indicated.

Generally, the production of primary petrochemicals and polymers generate the smallest quantities of wastewater with flows increasing as the degree of processing progresses. Concentrations of contaminants follow approximately the same pattern with some exceptions. Of those listed, the largest amount of wastewater results from the production of dyes and pigments because of the multi-stage, small-batch operations which are very prevalent in this industry.

It is important to note the staging of the petrochemical industry. The basic raw materials for the industry are natural gas, refinery gases and liquid fractions. Of key interest in the industry are the so-called secondary raw materials; these material (and their sources) are shown below:

Secondary Raw Material	Source
Acetylene	Cracking or partial oxidation of either methane in natural gas or of higher paraffins
Methane	Natural gas
Higher Paraffins	Refinery gas streams or natural gas
Ethylene	Refinery gas streams, pyrolysis of propane and ethane or by thermal cracking of liquid hydrocarbons
Propylene	Refinery gas streams or by thermal cracking of liquid hydrocarbons
C_4 Hydrocarbons	Refinery gas streams or by thermal cracking of liquid hydrocarbons
Higher Olefins	Waxcracking
Aromatics	Liquid petroleum fraction recovery, dehydrogenation, hydrogenation
Carbon Monoxide	Partial oxidation of hydrocarbons
Hydrogen	Partial oxidation of hydrocarbons

From these basic raw materials the industry has created the variety of intermediates that are finally converted to plastics, elastomers, resins, solvents and other materials. The major chemicals which have been surveyed in this report may be listed as primary, secondary or tertiary intermediates or as primary polymers. This interrelation between chemicals is a typical feature of the petrochemical industry and this is illustrated in the several charts (Figures 1, 2 and 3) which show the intricate relationship between the chemicals.

Appendix C contains an individual listing of 29 different petrochemical products together with associated descriptions of raw materials, processing waste generation and elimination aspects, and anticipated five-year growth projections for each product.

Clean Wastewaters

Clean waters, which are basically uncontaminated and can be discharged untreated, are not included in the total flows given in Table VII. Cooling water and steam condensates are the primary sources of such water, and a typical breakdown is given in Table VIII. Also included is an indication of potential pollutants and associated sources and concentrations. Although these clean wastewaters are relatively uncontaminated and exert little pollutional effect (except thermal) on the environment, care must be exercised to prevent contamination of these streams.

The thermal effects cannot be ignored. Effluent heat loads can adversely affect the surface receiving waters, causing decreased oxygen solubility and greater oxygen utilization. Both of these significantly reduce the ability of the receiving water to assimilate waste loads. Through the use of cooling towers, the quantity of high-temperature wastewaters discharged has been greatly reduced, because the cooled water can be recirculated in-plant. For the chemical industry, the thermal load exerted by the effluent from the secondary treatment facilities is generally restricted by the maximum temperature limitations of the biological treatment system and is thus of less concern.

The segregation of clean wastewater flows is widely practiced throughout the organic chemical industry, as a result of overall wastewater treatment economics and regulatory requirements. Although there is a limited possibility that wastewater flows can be further reduced by segregating additional clean waters, most major clean waters are currently collected and either recirculated or discharged separately in those organic chemical plants with secondary treatment facilities.

TABLE VII

WASTEWATER CHARACTERISTICS ASSOCIATED WITH SOME CHEMICAL PRODUCTS

Primary Petrochemicals	Flow gal/ton	BOD mg/L	COD mg/L	Other Characteristics
Ethylene	50- 1,500	100- 1,000	500- 3,000	phenol, pH, oil
Propylene	100- 2,000	100- 1,000	500- 3,000	phenol, pH
Primary Intermediates				
Toluene	300- 3,000	300- 2,500	1,000- 5,000	
Xylene	200- 3,000	500- 4,000	1,000- 8,000	
Ammonia	300- 3,000	25- 100	50- 250	oil, nitrogen
Methanol	300- 3,000	300- 1,000	500- 2,000	oil
Ethanol	300- 4,000	300- 3,000	1,000- 4,000	oil, solids
Buthanol	200- 2,000	500- 4,000	1,000- 8,000	heavy metals
Ethyl Benzene	300- 3,000	500- 3,000	1,000- 7,000	heavy metals
Chlorinate Hydrocarbons	50- 1,000	50- 150	100- 500	pH, oil, solids
Secondary Intermediates				
Phenol, Cumene	500- 2,500	1,200-10,000	2,000-15,000	phenol, solids
Acetone	500- 1,500	1,000- 5,000	2,000-10,000	
Glycerin, Glycols	1,000- 5,000	500- 3,500	1,000- 7,000	
Urea	100- 2,000	50- 300	100- 500	
Acetic Anhydride	1,000- 8,000	300- 5,000	500- 8,000	pH
Terephtalic Acid	1,000- 3,000	1,000- 3,000	2,000- 4,000	heavy metals
Acrylates	1,000- 3,000	500- 5,000	2,000-15,000	solids, color, cyanide
Acrilonitrile	1,000- 10,000	200- 700	500- 1,500	color, cyanide, pH
Butadiene	100- 2,000	25- 200	100- 400	oil, solids
Styrene	1,000- 10,000	300- 3,000	1,000- 6,000	
Vinyl Chloride	10- 200	200- 2,000	500- 5,000	
Primary Polymers				
Polyethylene	400- 1,600		200- 4,000	solids
Polypropylene	400- 1,600		200- 4,000	
Polystyrene	500- 1,000		1,000- 3,000	solids
Polyvinyl Chloride	1,500- 3,000	50- 500	1,000- 2,000	
Cellulose Acetate	10- 200	500- 2,000	1,000- 5,000	
Butyl Rubber	2,000- 6,000	800- 2,000	2,500- 5,000	
Dyes and Pigments	50,000-250,000	200- 400	500- 2,000	heavy metals, color, solids, pH
Miscellaneous Organics				
Isocyanate	5,000- 10,000	1,000- 2,500	4,000- 8,000	nitrogen
Phenyl Glycine	5,000- 10,000	1,000- 2,500	4,000- 8,000	phenol
Parathion	3,000- 8,000	1,500- 3,500	3,000- 6,000	solids, pH
Tributyl Phosphate	1,000- 4,000	500- 2,000	1,000- 3,000	phosphorus

SOURCE: Roy F. Weston and REA

TABLE VIII COMPOSITION OF TYPICAL CLEAN WATER EFFLUENT

Water Sources	% of Total Waste Water	Flow Range (GPM)	POTENTIAL POLLUTANTS Sources	Type	Concentration Range (ppm)
Cooling Water (excluding sea water)	40-80	100-10,000 (500-200,000 gal. water ton product)	Process leaks: Bearings, exchangers, etc.	Extractables	1- 1000
				Mercaptans	
				sulfides	
				Phenols	0-1000, but usually less than 1 ppm
				Cyanide	
				Mics. N. compounds	
				Acids	
			Water treatment	Chromate	0-60
				Phosphate	0-60
				Heavy metals	0-30
				Fluoride	0-30
				Sulfate	100-10,000
				Biocides, algacides	0-50
				Misc. organics	0-100
			Scrubbed from air through tower	Hydrogen sulfide	
				Sulfur dioxide	0- 1000
				Oxides of nitrogen	
				Ammonia	
			Make-up Water	Particulates	0-300
				Total dissolved solids	100-5000
				Particulates	0-100
				Phosphates	0-5
Steam Equipment	10	50-1,000		Fluoride	0-2
			Boiler Blowdown	Total dissolved solids	500-10,000
				Particulates	5-300
				Extractables	0-10
				Phosphate	1-50
				Sulfite	0-50
				Sulfide	0-5
				Misc. organic compounds	0-200
				Misc. N compounds	1-100
				Heavy metals	0-10
			Waste Condensate	Alkalinity	50-400
				Extractables	0-100
				Ammonia	0-10

SOURCE: Freedman, A. J., et. al., Natl. Petroleum Refiners Assoc., Tech. GC-67-19, 1967

VI. WASTEWATER TREATMENT METHODS

The production of organic chemicals results in many types of contaminated wastewaters, and the treatment methods employed cover the range of known practical techniques. In-plant control is the first step in instituting treatment practices. Such controls include the salvage of unreacted chemicals, recovery of by-products, multiple reuse of water, good housekeeping techniques to reduce leaks and spills, and changes in processing methods. These controls can result in reducing the concentrations of almost all potential pollutants and can, most importantly, reduce the volumes of wastewaters requiring treatment. Physical treatment methods such as sedimentation or flotation are used primarily to remove coarse suspended matter and floating oils and scums. Filtration is used as a form of tertiary treatment for reuse or as a pretreatment for deep-well injection. Chemical treatment is used primarily as a pretreatment prior to sedimentation, filtration, or biological treatment. Biological treatment is most widely used in the industry due to the nature of the wastes, that is, their general susceptibility to biodegradation as evidenced by relatively high BOD values.

A general treatment process sequence substitution diagram is given in Figure 4.

This generalized diagram is broken up into two general treatment trains, one for "dilute" and the other for "concentrated" wastewater streams. Although this distinction is very arbitrary and in many smaller plants all contaminated streams are collected for joint treatment, the primary application is to larger plants where treatment economics justify segregation and individual disposal.

The generalized diagram does not include all possible treatment unit processes; only those widely prevalent or often considered in the organic chemicals industry are included. The specific unit processes employed and the removal efficiencies obtainable in any given treatment system vary with the nature and flow of the wastewater stream.

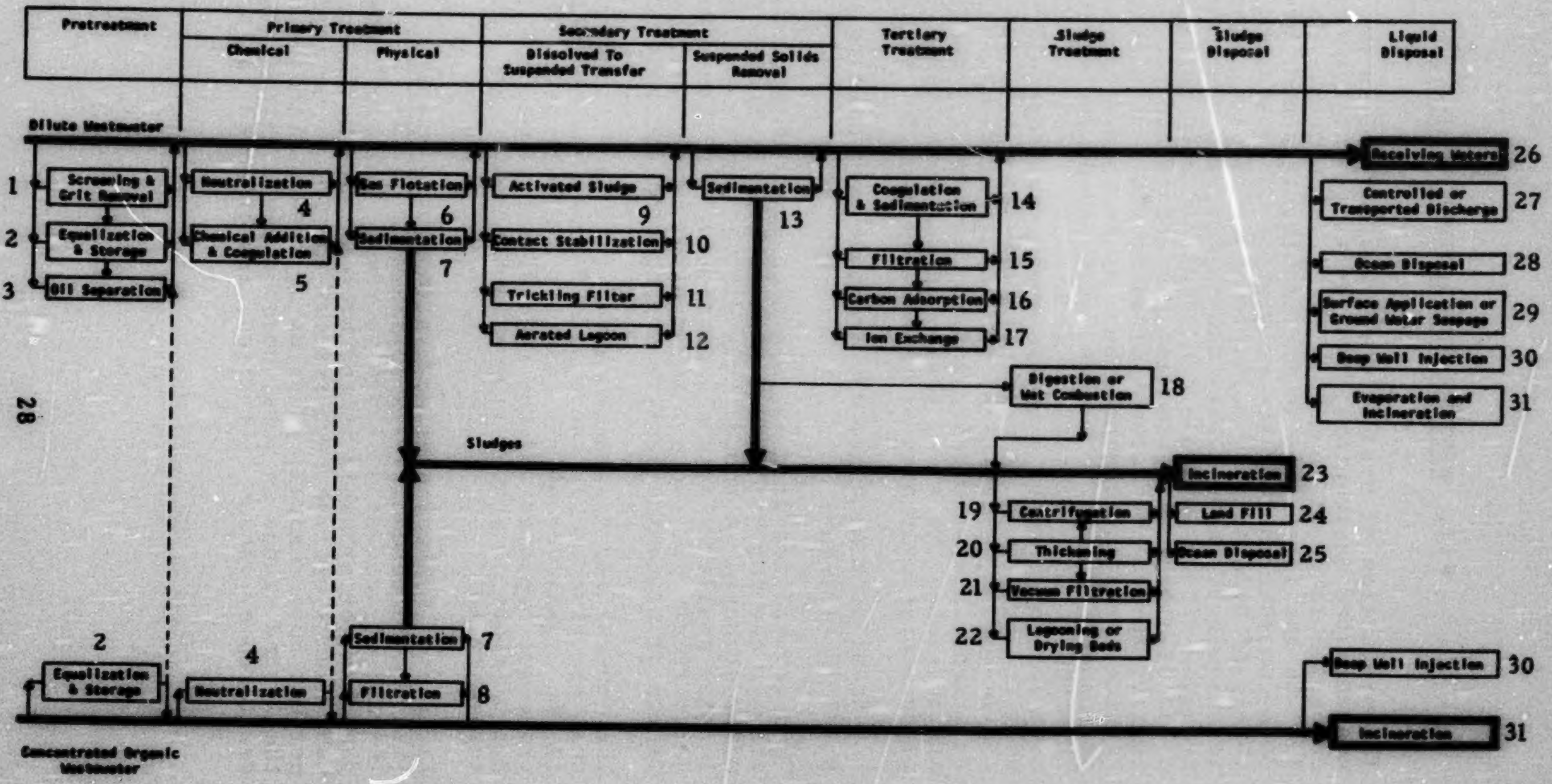
Example of Conventional Activated Sludge System
(Process Sequence: 4-7-9-13-18-20-21-24-28)

The use of activated sludge to remove soluble biodegradable organic matter probably is the predominant treatment process. Many plants utilize such systems and report performances of 88 percent BOD_5 removal. When using the activated sludge process, the wasted sludge is first aerobically digested, then thickened, dewatered by vacuum filtration, and disposed to landfill.

Figure 4

Chemical Industry

Wastewater Treatment Sequence/Processes Substitution Diagram


Pretreatment
Primary Treatment
Chemical
Physical
Secondary Treatment
Dissolved To Suspended Transfer
Suspended Solids Removal
Tertiary Treatment
Sludge Treatment
Sludge Disposal
Liquid Disposal
Dilute Wastewater
1 Screening & Grit Removal
2 Equalization & Storage
3 Oil Separation
Neutralization 4
Chemical Addition & Coagulation 5
Gas Flotation 6
Sedimentation 7
Activated Sludge 9
Contact Stabilization 10
Trickling Filter 11
Aerated Lagoon 12
Sedimentation 13
Coagulation & Sedimentation 14
Filtration 15
Carbon Adsorption 16
Ion Exchange 17
Digestion or Wet Combustion 18
Sludges
19 Centrifugation
20 Thickening
21 Vacuum Filtration
22 Lagooning or Drying Beds
Incineration 23
Land Fill 24
Ocean Disposal 25
Receiving Waters 26
Controlled or Transported Discharge 27
Ocean Disposal 28
Surface Application or Ground Water Seepage 29
Deep Well Injection 30
Evaporation and Incineration 31
2 Equalization & Storage
4 Neutralization
Sedimentation 7
Filtration 8
Deep Well Injection 30
Incineration 31
Concentrated Organic Wastewater

Example of System Employing Contact-Stabilization (Process Sequence: 2-3-4-10-13-19-23-27)

Contact-stabilization systems are not widely used, but this method has promise of greater application in the very near future, because it offers some economic advantages over conventional activated sludge treatment. For sludge removal, this system employs centrifugation and incineration.

Example of Aerated Lagoon System (Process Sequence: 1-2-7-11-24-26)

Where applicable, an aerated lagoon system can prove to be quite economical. Many plants employ such a system. However, the solids that build up in both the settling pond and the aerated lagoon have to be manually removed.

Example of Deep-Well Disposal (Process Sequence: 1-2-8-30)

In the areas where suitable geological formations are available and where regulations permit, deep-well injection is a suitable means of ultimate disposal of wastes. Filtration and other pretreatment are often required to prevent plugging the formation. This technique is rather widely used in the industry.

Figure 5 shows a flow diagram for a typical wastewater treatment system presently handling the effluent from a large multiproduct organic chemical plant.

JOINT INDUSTRIAL-MUNICIPAL TREATMENT

According to the Census of Manufactures (1963) 45 billion gallons per year of water from the chemicals industry is discharged to municipal sewers out of a total of 1.8 trillion gallons taken in or about 2.4%. These data are supported by other studies by chemical industry groups, but apply to plants reporting water use of at least 20 million gallons per year or having more than 100 employees. The employment distributions in 641 organic chemical plants in 1963 is shown in Table IX.

Figure 5

FLOW DIAGRAM OF
WASTEWATER TREATMENT FACILITIES

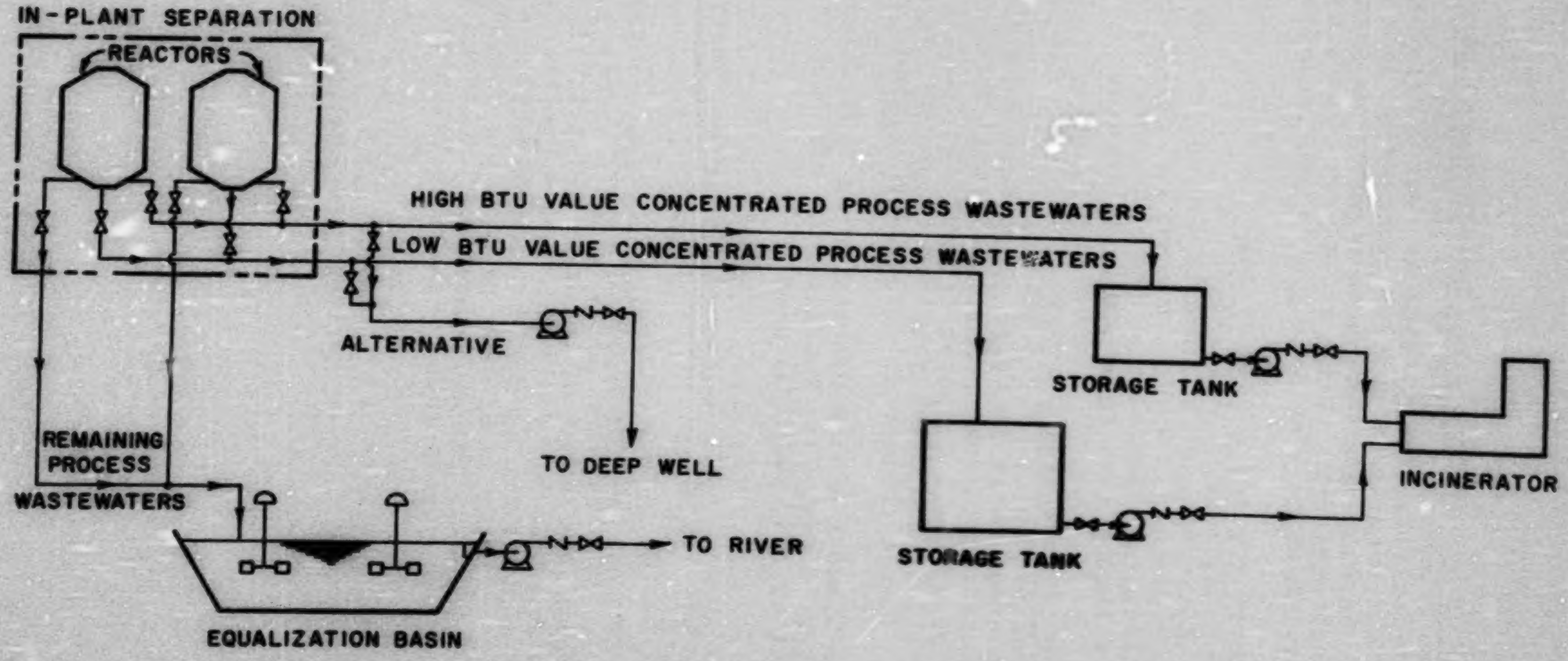

IN-PLANT SEPARATION
REACTORS
HIGH BTU VALUE CONCENTRATED PROCESS WASTEWATERS
LOW BTU VALUE CONCENTRATED PROCESS WASTEWATERS
ALTERNATIVE
TO DEEP WELL
REMAINING PROCESS WASTEWATERS
TO RIVER
EQUALIZATION BASIN
STORAGE TANK
STORAGE TANK
INCINERATOR

TABLE IX

SIZE OF CHEMICAL PLANTS BY EMPLOYMENT

No. of Plants	Employment
162	1-4
58	5-9
79	10-19
104	20-49
68	50-99
79	100-200
38	250-499
29	500-999
17	1000-2499
7	2500+

SOURCE: Census of Manufactures,

The smallest plants tend to be in or near urban centers and discharge their wastewaters to municipal sewers; these same plants, however, tend to be users of relatively little water. Plants in the organic chemicals industry are distributed according to total water intake as shown in Table X, based upon a total of 561 plants surveyed in 1963.

TABLE X

WATER INTAKES OF ORGANIC CHEMICALS PLANTS

No. of Plants	Water Intake, million gals. per year
260	less than 1
63	1-9
27	10-19
60	20-99
151	more than 100

SOURCE: Census of Manufactures,

From these data it can be seen that many chemical plants are not included in the calculation of the 2.4% discharge to municipal sewers, but that these small plants individually use relatively little water. If it were assumed that all of the organic chemicals plants taking in less than 20 million gallons of water per year discharge all of their intake water to sewers, a total of about 49.8 billion gallons per year of wastewater might be expected to have been discharged to municipal sewers by the organic chemical industry in 1963. This figure is based upon the assumption that municipal sewer discharges by the large plants consist mainly of contaminated wastewaters and that discharges from the smaller plants are entirely process water, presumed to be contaminated, and that SIC 2515 and 2818 account for 92.5% of the organic chemical industry.

On the basis of an annual production of about 71 billion pounds by the organic chemicals industry in 1963, municipal discharges might be expected to be about 1400 gallons per ton of production for the industry as a whole.

Treatment costs play an important role in governing the expansion of joint treatment participation. Rates established by municipalities vary widely. Where the municipal system is small and additional contributors would overload the treatment plant, high rates are imposed to discourage industrial contributors. Examples of low, average, and high rates are given as follows:

1. Low - A major Atlantic coastal city applies the same rates to any industrial discharge as they do to domestic customers. This rate is based on 51 percent of the water charge, which currently amounts to about $0.09/1,000 gallons. However, the wastewater characteristics have to be ascertained and acceptable for treatment prior to acceptance. Furthermore, the city can establish specific pretreatment requirements before accepting the wastewater for treatment in the municipal system.

2. Average - A small municipality in a North Atlantic State, with a 30 mgd treatment plant, charges the organic chemicals industry $0.40/1,000 gallons for a 0.75 mgd discharge.

3. High - In another North Atlantic State, the current industrial charge rate specified by the municipal regulations is $0.70/1,000 gallons for flows less than 0.03 mgd decreasing to $0.44/1,000 gallons for flows exceeding 0.57 mgd. In addition, there is a surcharge of $0.20/lb BOD$_5$ over 250 mg/l, $0.15/lb suspended solids over 300 mg/l, and $0.15/lb of chlorine demand above 5 mg/l.

4. In a major Midwestern city there is no charge for industrial wastes discharged to the municipal sewers; however, the wastewaters must have a degree of pretreatment as defined in the city ordnances.

The chemical industry has generally found that in-plant, separate treatment has economic advantages, particularly when significant quantities of contaminated wastewater are involved. No significant percentage increase is expected in the amount of organic chemical wastewaters that will be treated in joint systems in the near future.

VII. INDUSTRIAL WASTE TREATMENT PRACTICES DATA FORM

An important objective of this study has been to develop a generalized methodology for the determination of the cost-effectiveness of industrial waste treatment practices. The first requirement of any such generally applicable method is to format the input data in a uniform and consistent manner and to insure the adequacy of these data at an early stage, preferably at the actual time of acquisition. The data form presented here satisfies these primary requirements and was used in acquiring data from 53 organic chemicals plants; these data constitute one basis for this report.

The Industrial Waste Treatment Practices Data Form may be used for the acquisition of data upon which the cost-effectiveness of industrial waste treatment practices can be determined in general. Although the form has utility in tabulating data for a single plant or firm, the prime purpose is to format data for analysis in terms of general industry practices. The form is designed on the basis of the Defense Intelligence Agency's Formmatted File System, a punched-card system utilizing aperture cards for document incorporation. The system is capable of accepting subsequent additions of new data at points within the file and is readily revised within the file. Data formmatted in this system can be retrieved according to selected parameters, can be readily sorted and printed out according to selected parameters, and can be readily analyzed and correlated by machine computation.

The Industrial Waste Treatment Practices Data Form consists of nine or more data sheets corresponding to nine types of punched-cards; there is one each of cards 1, 2, and 5 for each form and provision for multiple cards 3, 4, 6, 7, 8 and 9 for each form. Data may be tabulated by a mark (X) within a labeled field, in terms of quantitative measures in indicated and/or coded units, or in terms of coded, qualitative information.

The nine data sheets comprising the Industrial Waste Treatment Practices Data Form are shown in Appendix A.

VIII. PLANT SURVEY DATA

The Industrial Waste Treatment Practices Data Form was used to tabulate data from 53 organic chemicals plants. Complete information was not obtainable for each plant, but all information obtained was used to the extent possible. This information was largely obtained from confidential reports, private communications, and pertinent literature.

Data on 37 plants for which adequate information was obtained are given in Appendix B in terms of the following parameters:

(X_1) Capital Costs of Treatment Facilities ($/1000 gpd)

(X_2) Operating Costs of Treatment Facilities ($/yr/1000 gpd)

(X_3) Efficiency of Critical Pollutant Removal (%)

(X_4) Capital Costs of Treatment Facilities ($/ton of Annual Production)

(X_5) Operating Costs of Treatment Facilities ($/yr/ton of Annual Production)

(X_6) Volume of Wastewater (gpd/ton of Annual Production)

In Table XI the characteristics of the wastewaters from the 53 plants surveyed are shown in terms of the effluent volume and the concentrations of BOD, COD, and suspended solids; the identification numbers generally correspond with the plant numbers used throughout this report. In Table XII the frequencies of certain wastewater treatment methods and of sludge treatment are shown for 41 of the plants surveyed.

The bar graphs in Figures 6 through 10 show distributions of various parameters for the plants surveyed. It is of particular significance that the distributions of wastewater volume and annual production are markedly skewed in the opposite directions and, although most of the plants surveyed were judged to be medium or large in terms of production, employment was relatively low in most cases. The level of technology in the surveyed plants was generally judged to be average or advanced, although the median age of the plants was 18 years. The explanation of such an apparent anomaly lies in the relatively short lives of chemical processes and equipment; replacement equipment and new processes installed in even the older plants tend to be of modern design.

TABLE XI

CHEMICAL WASTE CHARACTERISTICS

Identification Number	Principal Products	Q (mgd)	BOD_5 (mg/l)	COD (mg/l)	SS (mg/l)
2	Phthalic anhydride, maleic anhydride Plasticizers, H_2SO_4	0.002	-	200	24
3	Chemical warfare gas, chromium plating	0.001	200	1100	-
4	Terephthalic acid, isophthelic acid, dimethyl tenaphthalate	5.36	-	9800	10,600
5	Butadiene, Styrene, Polyethylene, Olefins	1.68	-	-	-
6	Phenol, Ethylene	2.0	300	1200	300
7	Acrylonitrile	0.302	-	1200	239
8	Fatty acids, esters, glycerol	0.10	10,000	14,000	-
9	Regenerated cellulose	1.41	-	-	-
10	Acetylene	-	-	-	-
11	Dyes, pigments, inks	0.452	227	-	93
12	Azo & Anthraquinine dyes	0.94	352	1760	152
13	Anthraquinine vat dyes	5.0	300	1160	-
14	Ethylene, Alcohols, Phenol	5.9	1700	3600	610
15	Benzene, Ethylene, Butyl Rubber, Butadiene, Xylene, Isoprene	14.7	91	273	-
16	Acrylonitrile, Acetonitrile, Hydrogen Cyanide	3.9	390	830	106
17	Terephthalic Acid	0.335	-	4160	-
18	Glycerine, Various Glycols	0.49	2810	-	-
19	Methyl & Ethyl parathion	0.075	3100	5000	80
20	Methyl isocyanate, Phosgene Diphenol Glycine	0.543	1146	3420	-
21	Urea, Ammonia, Nitric acid, NH_4NO_3	0.65	105	140	-

TABLE XI - Continued

Identification Number	Principal Products	Q (mgd)	BOD_5 (mg/1)	COD mg/1)	SS (mg/1)
22	Butadiene, styrene, propylene, polyolefin, adipic acid	1.38	5630	1230	225
23	Butadiene, alkylate, methylethyl ketone, styrene, maleic anhydride	2.0	1870	-	10
24	Butadiene, Maleic acid, Fumeric acid, Tetrahydrophthalic anhydride	3.605	959	1525	-
25	Diphenol carbonate, D-nitrophenol, benzene, Quinolin, H_2SO_4, Tear gas, Ditnitro benzoic acid	0.098	650	1380	-
26	Organo-phosphates, Esters, Resins Phosphorous chlorides	1.2	845	2040	322
27	Phenols	0.215	6600	13,200	-
28	500 Different products	3.2	360	500	673
30	Organic & Inorganic Chemicals	2.1	100	-	-
31	Phenols	0.22	6600	13,200	-
32	Additives for lubricating oils	0.20	465	1050	250
33	Polyethylene, ethylene oxide, ethand polypropylene	2.1	1385	2842	-
34	Acrylates, Insecticides, enzymes, Formaldehydes, Amines	1.06	1960	2660	80
35	Ethylene, propylene, butadiene, crude benzene, toluene	0.228	500	-	-
36	Acids, Formaldehyde, acetone, methanol, ketones, nitric acid, nylon salt, vinyl acetate acetaldehyde	3.46	530	10,130	160
37	Isocynates, Polyols, Urethane Foam	0.57	421	1200	50
38	Acetaldehyde	1.15	20,000	50,000	200

TABLE XI - Continued

Identification Number	Principal Products	Q (mgd)	BOD_5 (mg/l)	COD (mg/l)	SS (mg/l)
39	Acrylanitrile, phenol,Butadiene	1.817	-	29,100	-
	Ethylene, Propylene, Toulene, xylene	0.43	1300	1500	-
40	Acids, Formaldehyde, Acetone, methanol, ketones, alcohols, acetaldehyde	1.15	15,000	30,000	-
41	Petrochemicals	15.2	177	-	-
42	Acrylonitrile, butadiene, styrene, impact polystyrene, crystal polystrene	0.085	200	-	60
43	Ethylene, Propylene, Butadiene alpha-olefins, polyethylenes	0.750	155	380	120
44	Organic chemicals	1.4	2000	4800	900
45	Pharmaceuticals (Dallas WPCF 66)	0.037	14,000	-	500
46	Organic Chemicals	0.077	850	1700	300
47	2,4,5-T	0.005	15,000	21,000	700
48	2-4-D	0.005	15,000	23,000	348
49	Butadiene	0.288	-	350	300
50	Organic Chemicals	0.288	-	750	120
51	Olefins	0.288	-	320	400
52	Adipic acid	0.13	-	35,000	180
53	Hexamethylenediamine	0.13	-	113,000	1200
54	Petro Chemicals	0.02	-	40,000	30
55	Petro Chemicals	0.17	24,000	39,000	-

TABLE XII

REPORTED UNIT PROCESS BREAK-DOWNS

Plant No.	Oil Sep.	Eq.	Coag.-Sed.	Neut.	A.L.	A.S.	Sludge treatment		Products
							yes	no	
1	x		x			x	x		Dye chem.
2		x	x			x		x	Dye chem.
3		x	x		x				Dye chem.
4	x			x		x	x		Petro chem.
5	x			x		x	x		Petro. chem.
6					x				Org. chem.
7			x						Org. chem.
8		x				x	x		Org. chem.
9				x					Org. chem.
10		x							Org. chem.
11		x		x		x		x	Org. chem.
12	x			x		x	x		Org. chem.
13		x	x						Org.&inor.chem.
14	x								Petro chem.
15		x		x		x		x	Org.&inor.chem.
16	x					x		x	Petro chem.
17				x	x				monomers-polymer
18	x		x	x					Petro chem.
19									Petro chem.
20									Org. chem.
21			x	x	x				chem.
22	x	x	x		x	x	x		Petro chem.
23	x		x						Petro chem.
24	x					x		x	Phenol
25	x								
26			x			x	x		Misc. chem.
27	x					x		x	Petro chem.
28	x		x	x					Petro. chem.
29	x				x				Petro. chem.
30	x		x	x	x				Petro. chem.
31			x		x				Misc. chem.
32	x								Petro. chem.
34	x					x	x		cyclic chem.
35			x						Org. chem.
36	x					x		x	Org. chem.
37			x						Cyclic chem.
38	x		x						Petro chem.
39			x		x				Org. chem.
40	x		x	x					Org. chem.
41				x					Org. chem.

Number industries reporting specified unit processes:

20 8 18 13 9 15 8 7

Figure 6

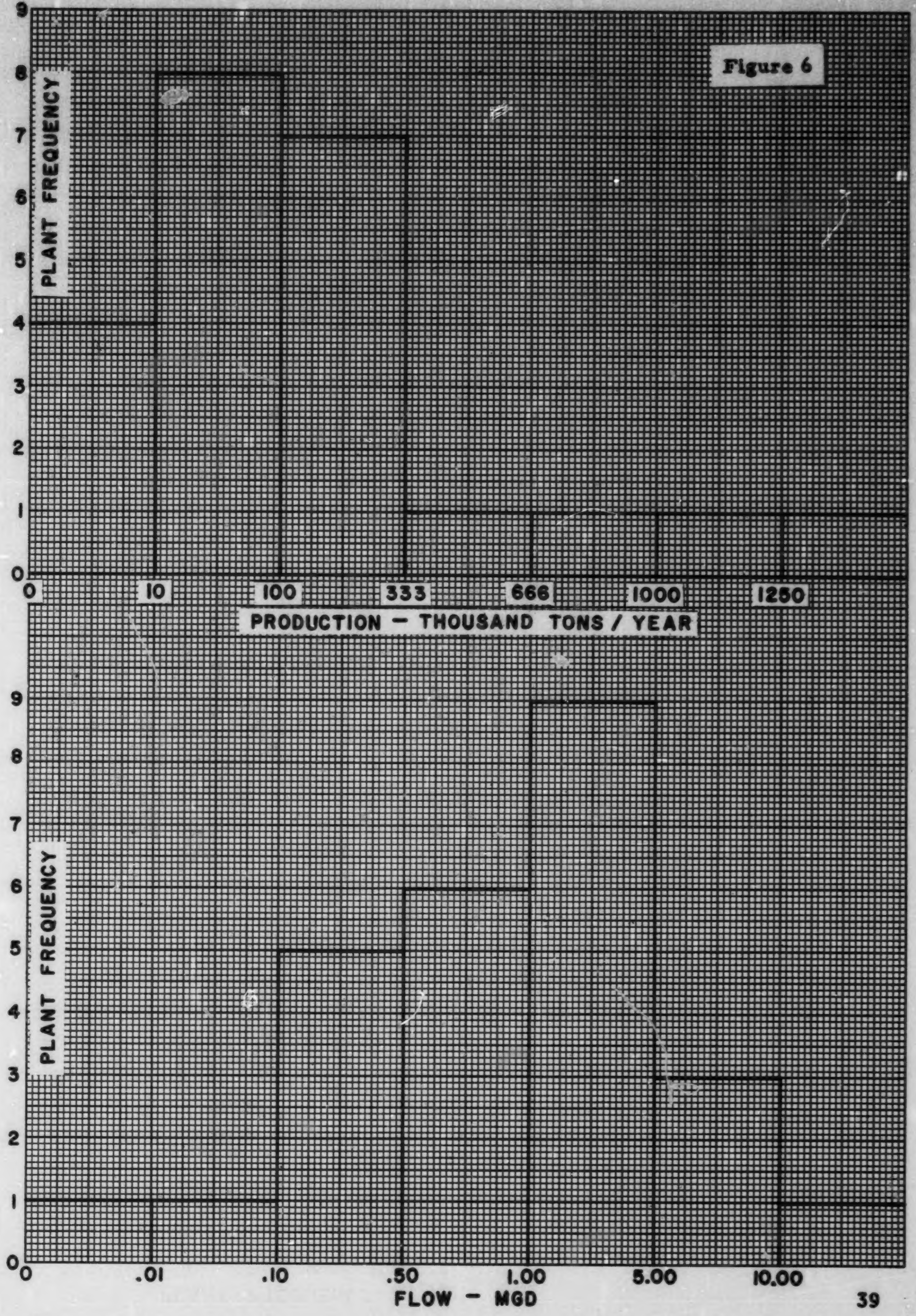

PLANT FREQUENCY
9
8
7
6
5
4
3
2
1
0
0
10
100
333
666
1000
1250
PRODUCTION — THOUSAND TONS / YEAR
PLANT FREQUENCY
9
8
7
6
5
4
3
2
1
0
0
.01
.10
.50
1.00
5.00
10.00
FLOW — MGD

Figure 7

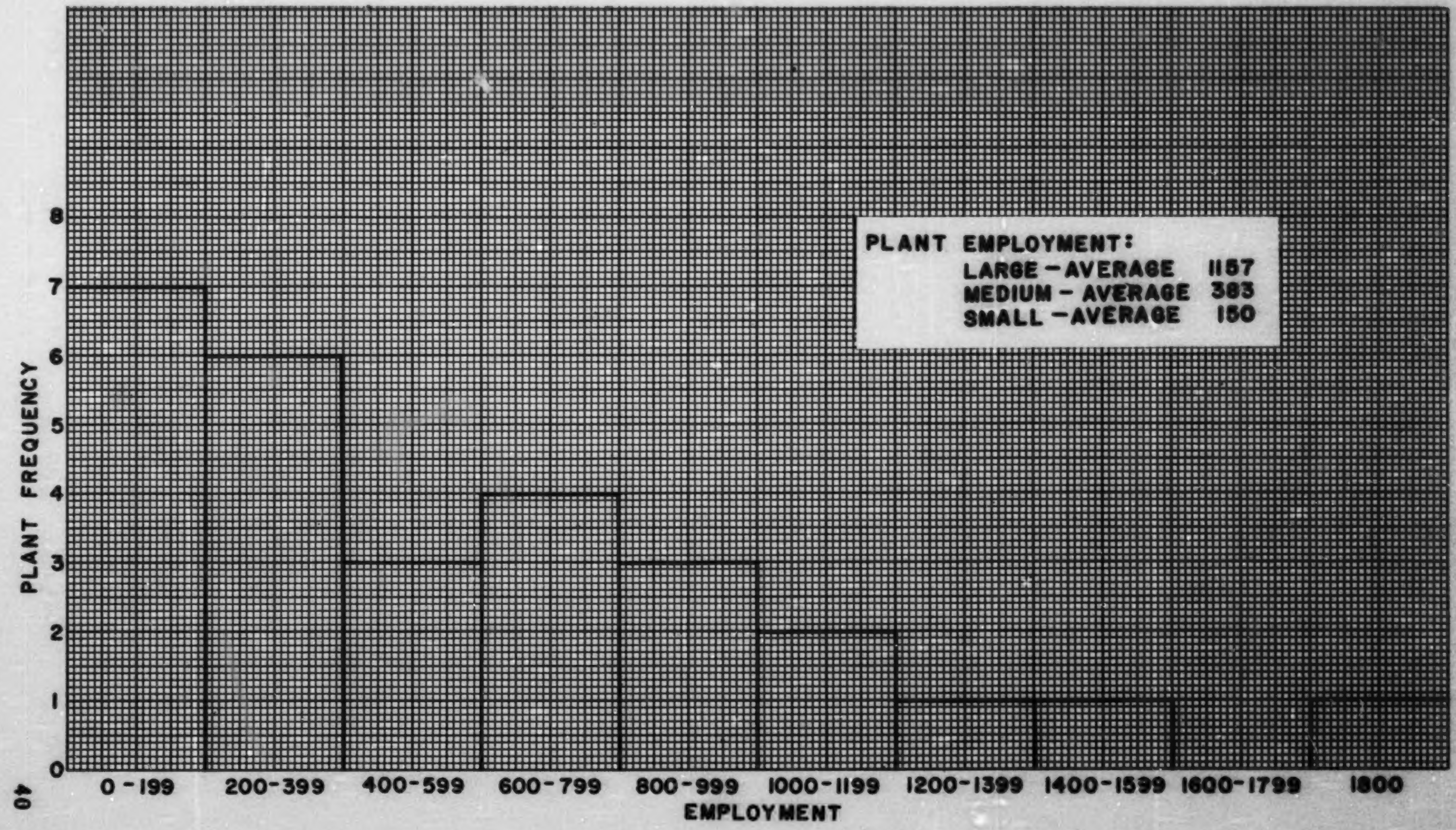
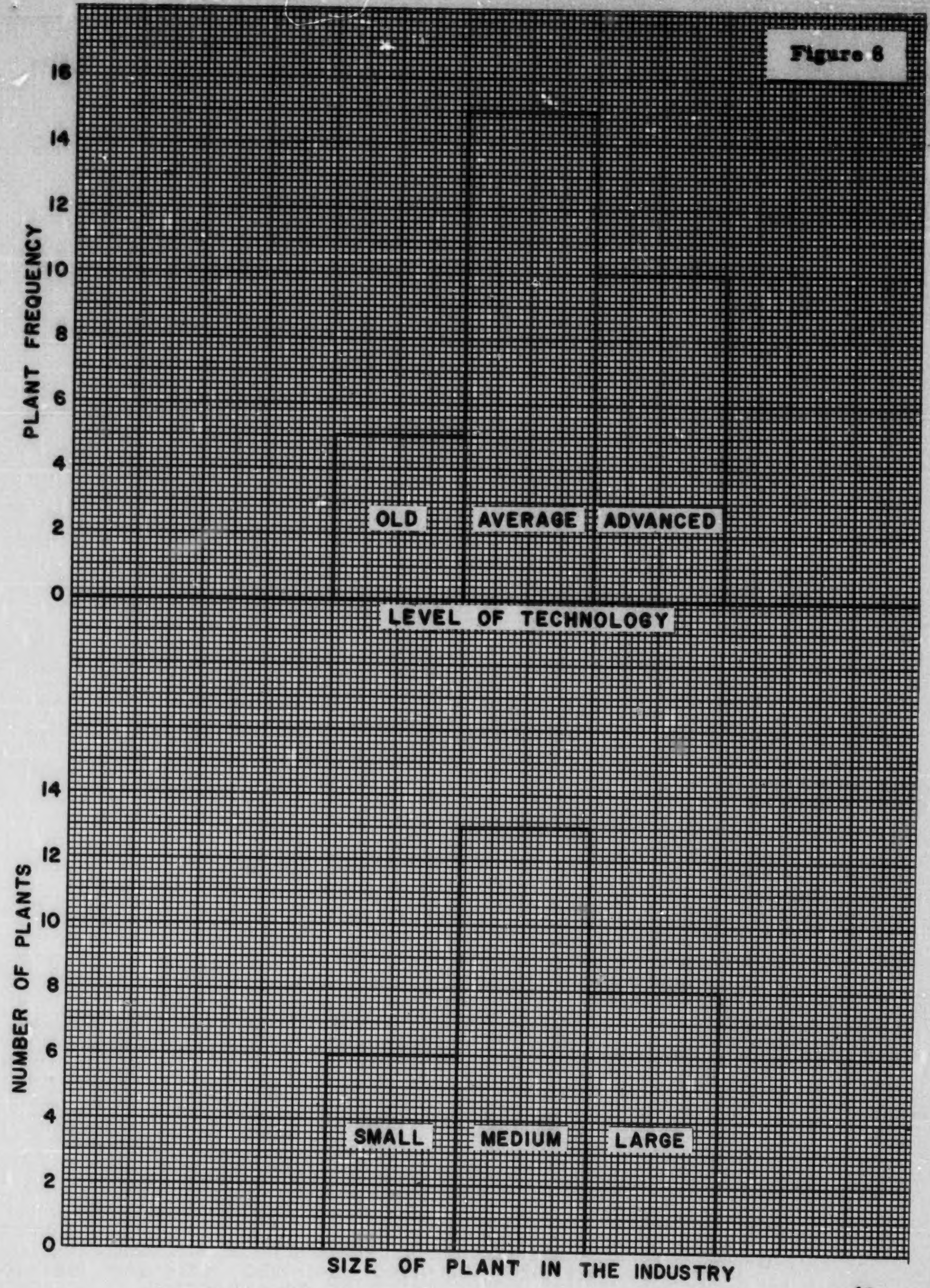
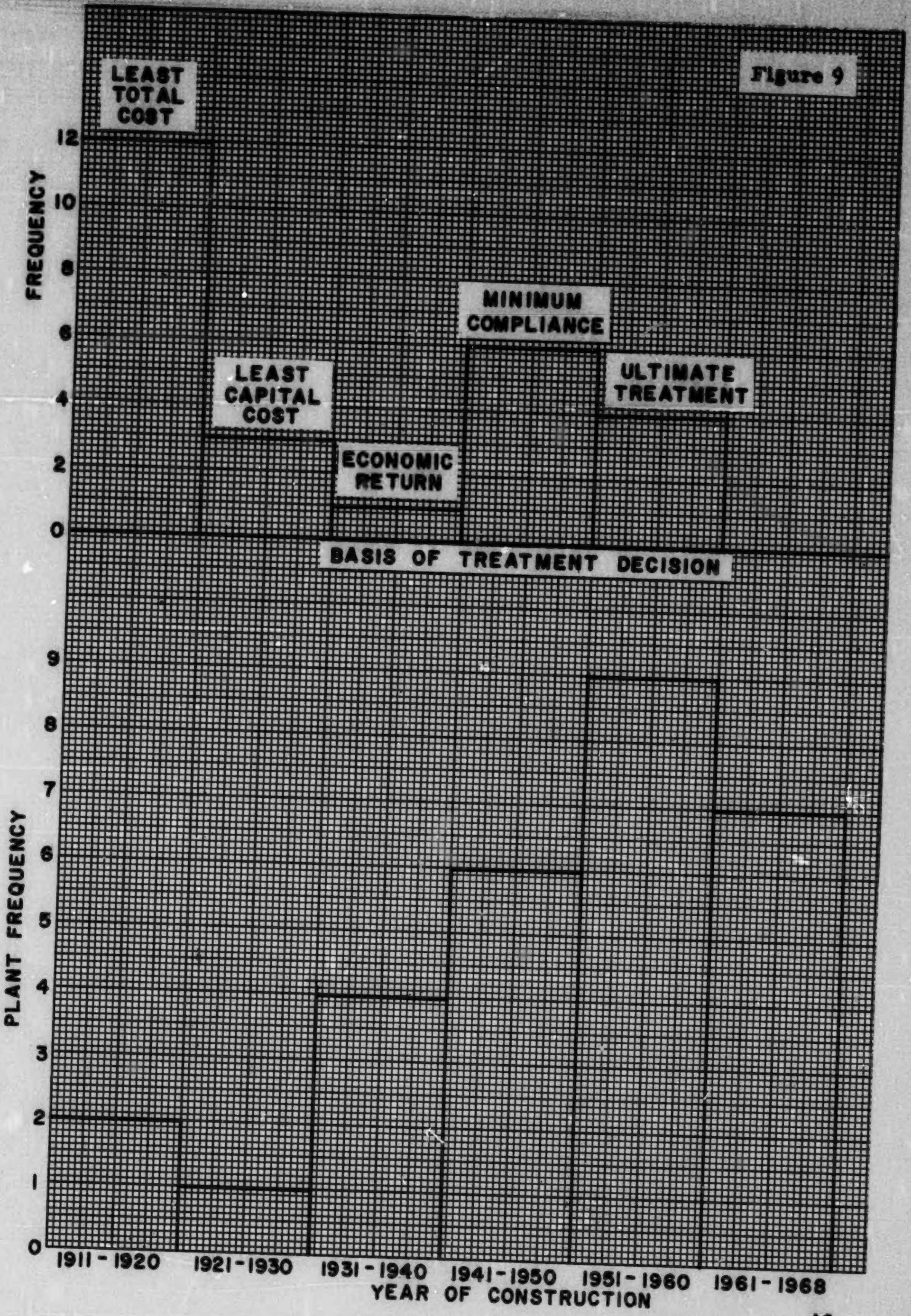

PLANT EMPLOYMENT:
LARGE - AVERAGE 1157
MEDIUM - AVERAGE 383
SMALL - AVERAGE 150
PLANT FREQUENCY
0
1
2
3
4
5
6
7
8
0 - 199
200-399
400-599
600-799
800-999
1000-1199
1200-1399
1400-1599
1600-1799
1800
EMPLOYMENT

Figure 8



16
14
12
10
8
6
4
2
0
PLANT FREQUENCY
OLD
AVERAGE
ADVANCED
LEVEL OF TECHNOLOGY
14
12
10
8
6
4
2
0
NUMBER OF PLANTS
SMALL
MEDIUM
LARGE
SIZE OF PLANT IN THE INDUSTRY

Figure 9



LEAST TOTAL COST
LEAST CAPITAL COST
ECONOMIC RETURN
MINIMUM COMPLIANCE
ULTIMATE TREATMENT
FREQUENCY
0
2
4
6
8
10
12
BASIS OF TREATMENT DECISION
PLANT FREQUENCY
0
1
2
3
4
5
6
7
8
9
1911 - 1920
1921 - 1930
1931 - 1940
1941 - 1950
1951 - 1960
1961 - 1968
YEAR OF CONSTRUCTION

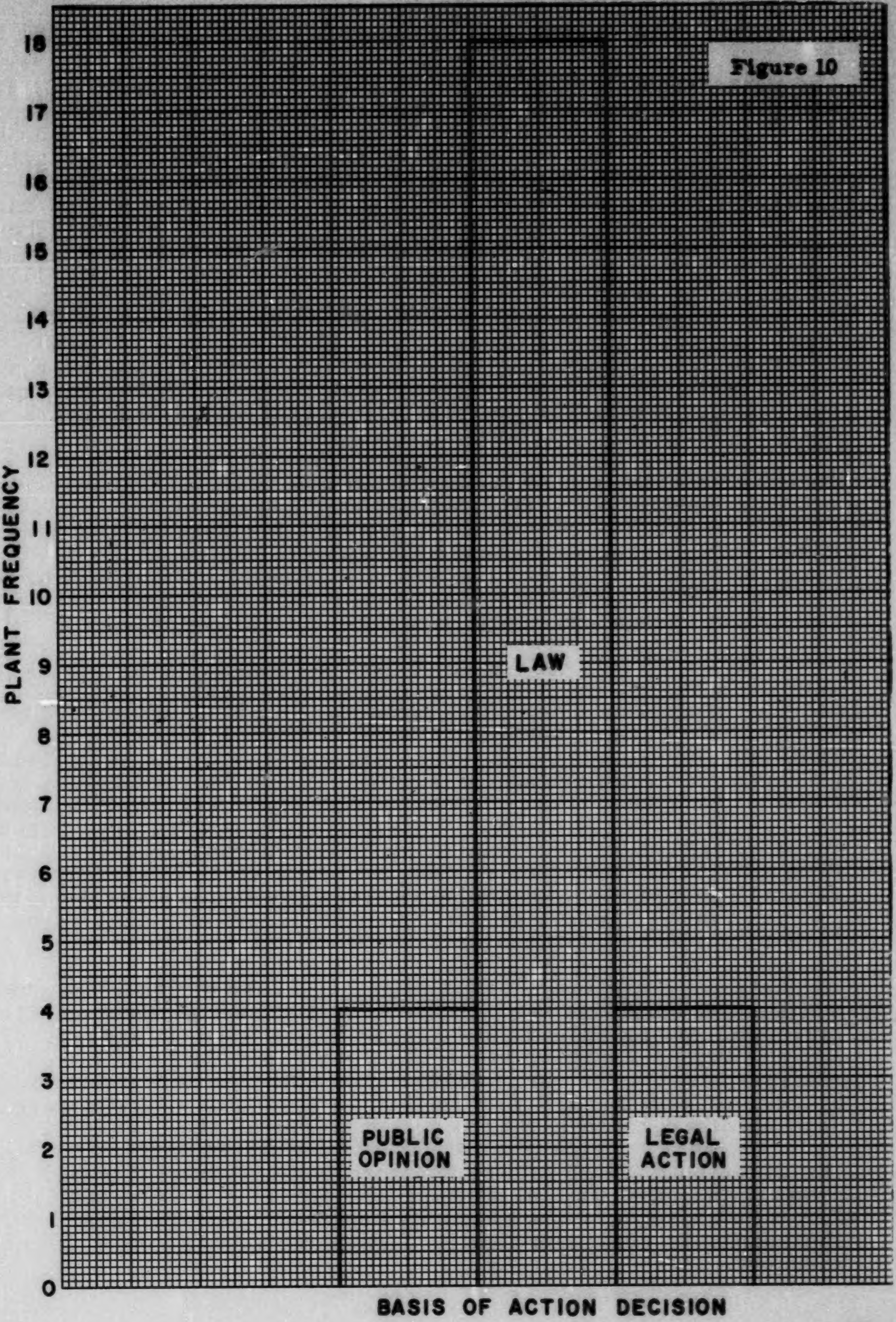


Figure 10
PLANT FREQUENCY
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
PUBLIC OPINION
LAW
LEGAL ACTION
BASIS OF ACTION DECISION

The most frequently reported basis for an action decision by the plant was that the legal requirement existed, although legal actions and public opinion cases were both mentioned. The particular treatment decision was based upon least total cost most often; least total cost generally means the least capital and operating costs over an arbitrary time period and is not evaluated in any sophisticated sense such as would be involved in considering savings in water use, etc.

According to the 1963 Census of Manufactures, Water Use in Manufacturing, 195 plants in SIC categories 2815 and 2818 took in for process use a total of 323 billion gallons of wastewater in 1964, an average of 1.66 billion gallons per year per plant, indicating an average wastewater flow of 4,564,000 gpd per plant. These data apply to the generally larger plants in these industries.

In 1963 there were a total of 641 plants in the organic chemicals industry. The 1963 production in the industry was about 71 billion pounds. These data indicate an overall average production in the industry of 110.76 million pounds or about 55,000 tons per year per plant. This figure has no meaning in any real sense because of the preponderant number of very small plants, and should be used, if at all, with caution.

There were 211 organic chemical plants having water intakes of more than 20 million gallons per year according to the 1963 census data. These are the larger plants which might be expected to average the above wastewater flow of 4,564,000 gpd. The industry survey data appended to the report covers 34 individual products which accounted for 117.187 billion pounds out of a total of 122.38 billion pounds (or about 95%) of organic chemicals produced in 1968; 238 plants are indicated to have accounted for this production, or an average plant production of 257,100 tons per year. The data of that survey also indicate an average capacity per product in individual plants of 231 million pounds per year (i.e., the total production of a product divided by the number of plants in which it is produced).

The data of this study, based upon 24 plants for which production and wastewater flows were determined, indicate an average flow of 2,318,692 gpd per plant, an average capacity of 306,097 tons/year, and an average capacity per product in individual plants of 267 million pounds per year. Considering that these parameters varied by several orders of magnitude within the sample, the sample can be considered to be a fair representation of the industry.

The distributions of plants by state and by capacities per product in individual plants for the entire industry and for the sample data are shown in Figures 11 and 12; again the sample is considered to be a fair representation of the industry.

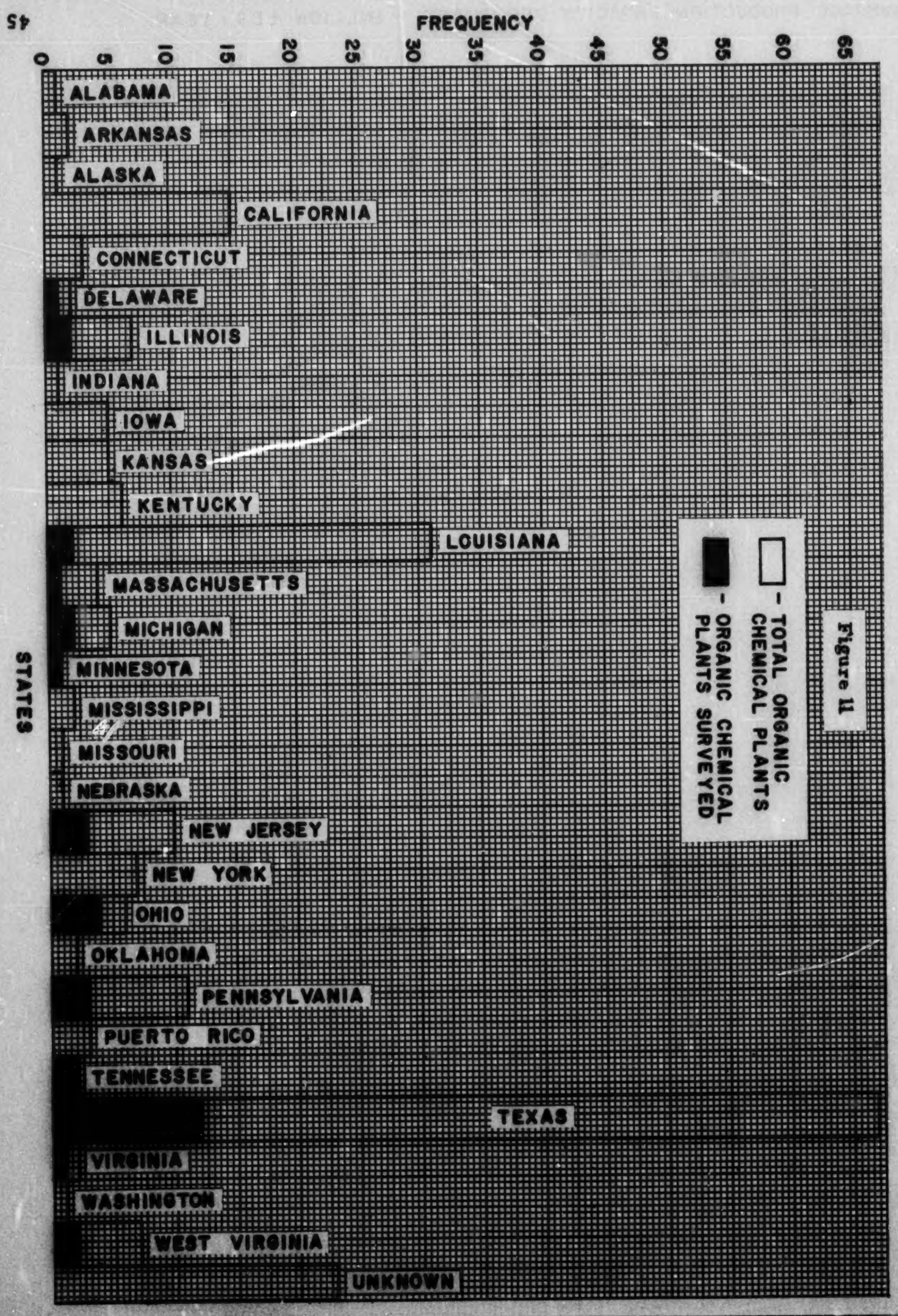


Figure 11

FREQUENCY
0
5
10
15
20
25
30
35
40
45
50
55
60
65
STATES
ALABAMA
ARKANSAS
ALASKA
CALIFORNIA
CONNECTICUT
DELAWARE
ILLINOIS
INDIANA
IOWA
KANSAS
KENTUCKY
LOUISIANA
MASSACHUSETTS
MICHIGAN
MINNESOTA
MISSISSIPPI
MISSOURI
NEBRASKA
NEW JERSEY
NEW YORK
OHIO
OKLAHOMA
PENNSYLVANIA
PUERTO RICO
TENNESSEE
TEXAS
VIRGINIA
WASHINGTON
WEST VIRGINIA
UNKNOWN
☐ - TOTAL ORGANIC CHEMICAL PLANTS
■ - ORGANIC CHEMICAL PLANTS SURVEYED

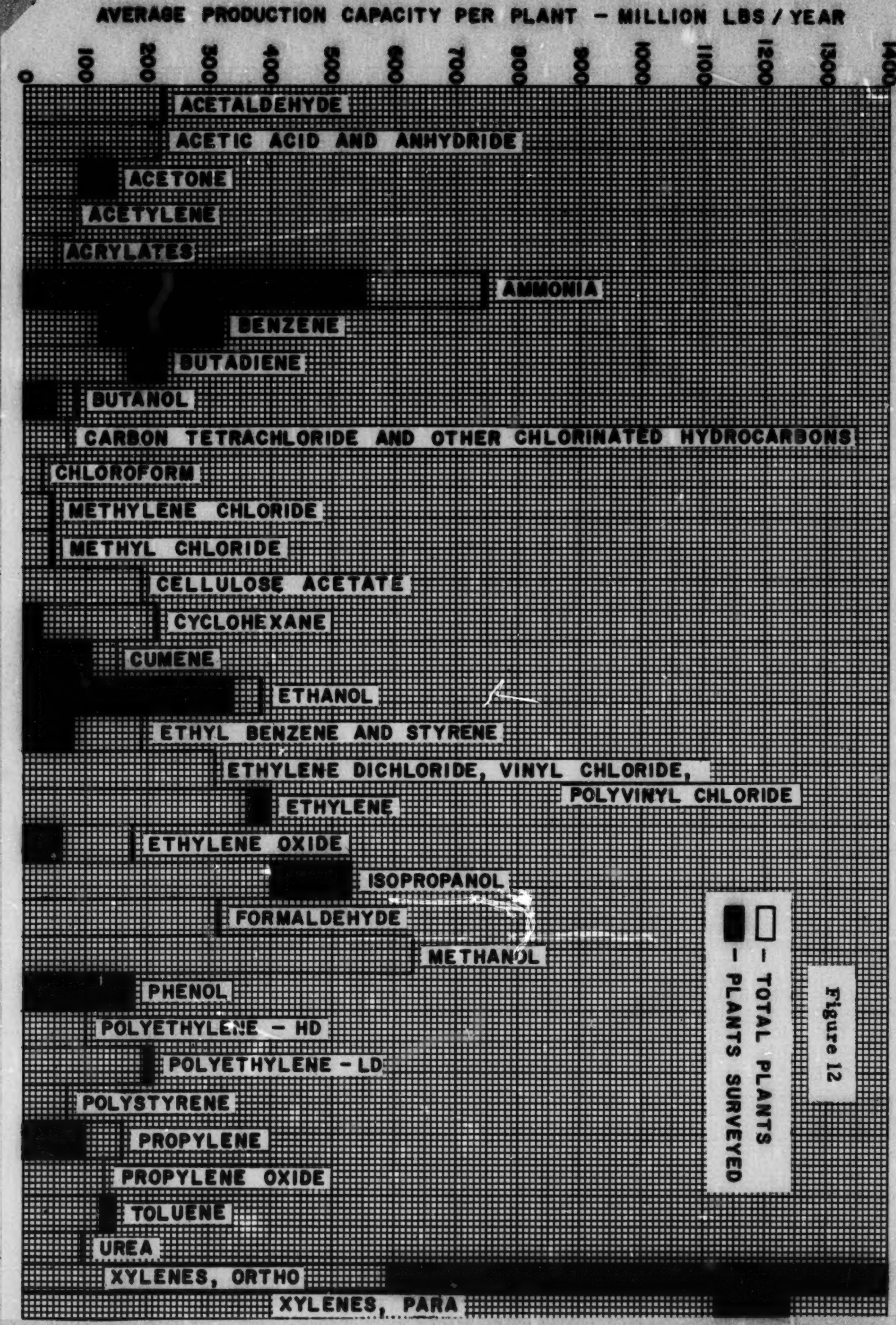

AVERAGE PRODUCTION CAPACITY PER PLANT - MILLION LBS / YEAR
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
ACETALDEHYDE
ACETIC ACID AND ANHYDRIDE
ACETONE
ACETYLENE
ACRYLATES
AMMONIA
BENZENE
BUTADIENE
BUTANOL
CARBON TETRACHLORIDE AND OTHER CHLORINATED HYDROCARBONS
CHLOROFORM
METHYLENE CHLORIDE
METHYL CHLORIDE
CELLULOSE ACETATE
CYCLOHEXANE
CUMENE
ETHANOL
ETHYL BENZENE AND STYRENE
ETHYLENE DICHLORIDE, VINYL CHLORIDE, POLYVINYL CHLORIDE
ETHYLENE
ETHYLENE OXIDE
ISOPROPANOL
FORMALDEHYDE
METHANOL
PHENOL
POLYETHYLENE - HD
POLYETHYLENE - LD
POLYSTYRENE
PROPYLENE
PROPYLENE OXIDE
TOLUENE
UREA
XYLENES, ORTHO
XYLENES, PARA
☐ - TOTAL PLANTS
■ - PLANTS SURVEYED

Figure 12

The survey data were examined for significant relationships between the various parameters of plant operation and/or waste treatment practices by means of multiple regression analyses made using both the absolute values of the variables and the logarithm of each variable. The results of the regression analyses are discussed below with the intent of indicating which relationships are of significance.

Data for 18 plants were analyzed in terms of the calculated parameters X_1, X_2, X_3, X_4, X_5, X_6 defined previously. Two statistically significant relationships were found at the 0.900 level of significance.

The capital costs of waste treatment facilities in a plant were found to be a logarithmic function of the wastewater volume; the regression equation is:

$$\log(X_4) = 1.1145 + 1.1559 \log (X_6) \qquad (1)$$

where: X_4 = Capital Costs of Treatment Facilities ($/ton of Annual Production)

X_6 = Volume of Wastewater (gpd/ton of Annual Production)

Of the variation in X_4, 80% is explained by X_6 alone ($R^2 = 0.7993$) and the variance of X_4 is reduced by an order of magnitude ($S_y = 2.3054$; $S_E = 1.0690$).

Operating costs of treatment facilities in a plant were found to be a logarithmic function of capital costs of treatment facilities; the regression equation is:

$$\log(X_5) = 1.8977 + 0.9293 \log (X_4) \qquad (2)$$

where: X_5 = Operating Costs of Treatment Facilities ($/yr/Ton of Annual Production)

Of the variation in X_5, 78% is explained by X_4 ($R^2 = 0.7826$) and the variance in X_5 is reduced by an order of magnitude ($S_y = 2.2765$; $S_E = 1.0964$).

Using all of the data available as appropriate, no statistically significant relationships were found between the efficiencies of critical pollutant removal and the other parameters. At a low level of significance, however, the capital costs of treatment facilities were indicated to be the major determinant of removal efficiencies.

With the data of 40 unit treatment operations no significant relationships were found between efficiencies of critical pollutant removals and costs per unit volume of wastewater.

Unit operating costs were found to be related to unit capital costs for individual systems at the 0.900 level of significance according to the following regression equation:

$$X_2 = -76.7181 + 0.2611 (X_1) \qquad (3)$$

where: X_1 = Capital Costs of Treatment Facilities (\$/1000 gpd)

X_2 = Operating Costs of Treatment Facilities (\$/yr/1000 gpd)

Of the variation in X_2, 92% is explained by X_1 ($R^2 = 0.9241$) and the variance in X_2 is reduced by more than 70% ($S_y = 1544$; $S_E = 431$).

IX. COSTS OF UNIT WASTEWATER TREATMENT METHODS

There are several processes which have been and are being applied to the treatment of wastewaters from the chemical industry. One of several biological treatment processes or a combination of processes will effect removal of the degradable organic compounds present in the waste. Anaerobic lagoons have been used where large land areas are available and will provide removals to BOD levels in the order of 100 mg/l. Aerated lagoons will reduce the BOD to levels in the order of 50 mg/l (depending on the temperature, the effluent BOD usually increasing during low temperature operation). The activated sludge process will provide high degree efficiency, with effluent BOD values of less than 25 mg/l.

In order to insure optimal and consistent secondary treatment performance, several pretreatment steps are frequently required. These include oil separation, neutralization and, in the case of high load variations, equalization. In cases where high concentrations of suspended solids are present in the waste, primary sedimentation is provided.

Figure 13 shows the processes most commonly employed for the treatment of chemical industry wastes. The treatment sequence has been broken down into pretreatment or primary treatment, secondary or biological treatment, tertiary treatment, and sludge handling and disposal.

For purposes of developing the cost-effluent quality relationships the effluent characteristics for the principal pollutional parameters have been estimated for each of the unit processes and are shown in Figure 13. No change in effluent characteristic (BOD, COD, S.S.) is attributed to neutralization or equalization. Primary sedimentation has been estimated to yield 65 percent and 10 percent removal of BOD and suspended solids respectively. The effluent BOD from the anaerobic lagoon, the aerated lagoon and the activated sludge process is estimated at 200, 100, and 25 mg/l, respectively. (This assumes average operating conditions at ambient temperature).

For each stage of the process, the effluent COD has been estimated from the relationship $COD_{EFF} = COD_{INF} - BOD_5$ removed/0.75

(It should be noted that the accumulation of non-biodegradable COD during the biological oxidation process has not been included).

The effluent characteristics for the tertiary treatment processes have been estimated from laboratory and field results on both municipal sewage and industrial wastewaters.

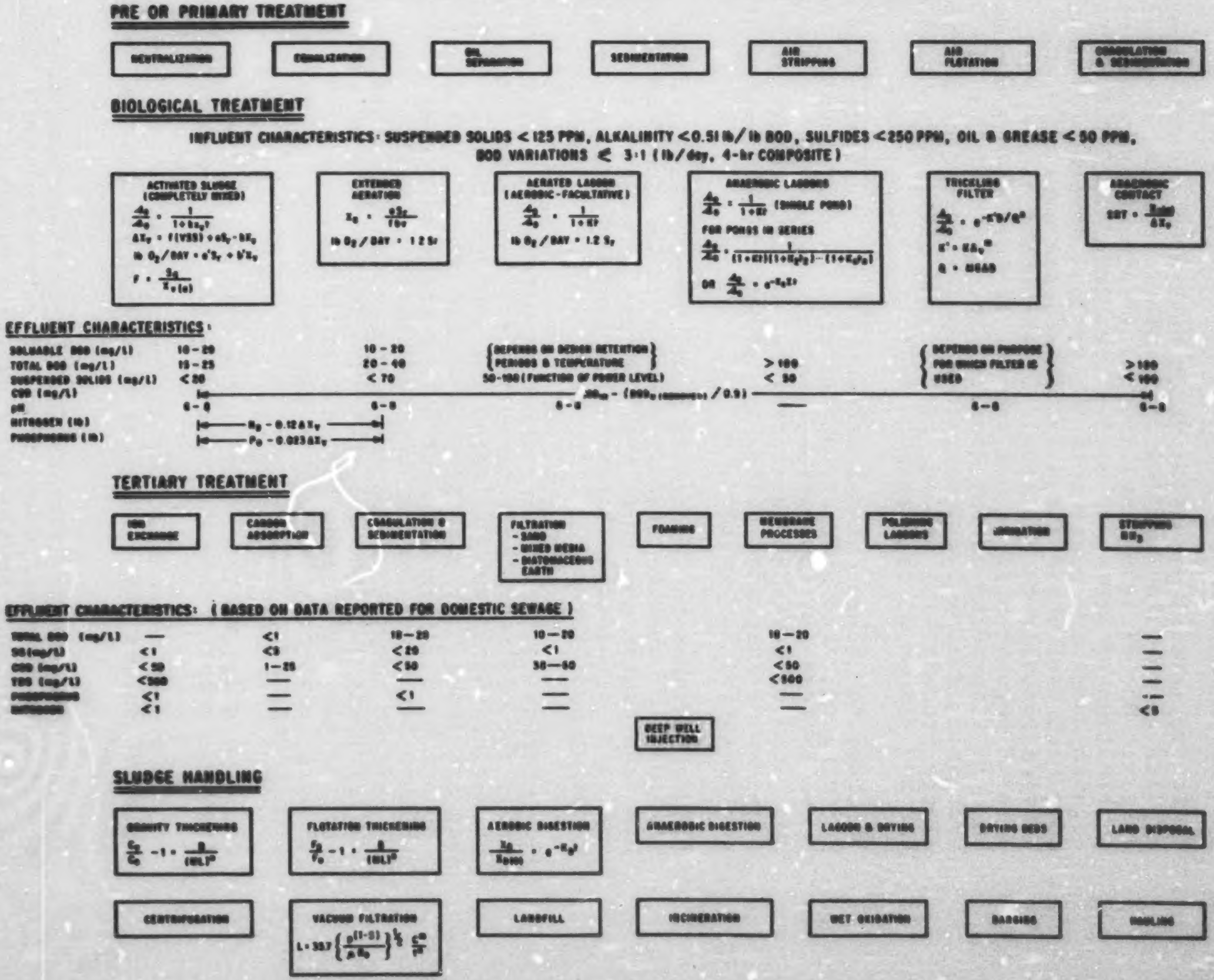


Figure 13

WASTEWATER TREATMENT PROCESSES & MODELS

PRE OR PRIMARY TREATMENT
NEUTRALIZATION
EQUALIZATION
OIL SEPARATION
SEDIMENTATION
AIR STRIPPING
AIR FLOTATION
COAGULATION & SEDIMENTATION
BIOLOGICAL TREATMENT
INFLUENT CHARACTERISTICS: SUSPENDED SOLIDS < 125 PPM, ALKALINITY <0.51 lb/lb BOD, SULFIDES <250 PPM, OIL & GREASE < 50 PPM,
BOD VARIATIONS ≤ 3:1 (lb/day, 4-hr COMPOSITE)
ACTIVATED SLUDGE (COMPLETELY MIXED)
lb O2/DAY
EXTENDED AERATION
lb O2/DAY = 1.2 Sr
AERATED LAGOON (AEROBIC-FACULTATIVE)
lb O2/DAY = 1.2 Sr
ANAEROBIC LAGOONS
(SINGLE POND)
FOR PONDS IN SERIES
OR
TRICKLING FILTER
Q = MGAD
ANAEROBIC CONTACT
SRT
EFFLUENT CHARACTERISTICS:
SOLUABLE BOD (mg/l)
TOTAL BOD (mg/l)
SUSPENDED SOLIDS (mg/l)
COD (mg/l)
pH
NITROGEN (lb)
PHOSPHORUS (lb)
10 - 20
15 - 25
< 20
6 - 8
10 - 20
20 - 40
< 70
6 - 8
DEPENDS ON DESIGN RETENTION PERIODS & TEMPERATURE
50-100 (FUNCTION OF POWER LEVEL)
6 - 8
> 100
< 30
—
DEPENDS ON PURPOSE FOR WHICH FILTER IS USED
6 - 8
> 100
< 100
6 - 8
N0 = 0.12 ΔXv
P0 = 0.023 ΔXv
TERTIARY TREATMENT
ION EXCHANGE
CARBON ABSORPTION
COAGULATION & SEDIMENTATION
FILTRATION
- SAND
- MIXED MEDIA
- DIATOMACEOUS EARTH
FOAMING
MEMBRANE PROCESSES
POLISHING LAGOONS
OZONATION
STRIPPING NH3
EFFLUENT CHARACTERISTICS: (BASED ON DATA REPORTED FOR DOMESTIC SEWAGE)
TOTAL BOD (mg/l)
SS (mg/l)
COD (mg/l)
TDS (mg/l)
PHOSPHORUS
NITROGEN
—
<1
<50
<500
<1
<1
<1
<3
1—25
—
—
—
10—20
<20
<50
—
<1
—
10—20
<1
30—60
—
—
—
10—20
<1
<50
<500
—
—
—
—
—
—
—
<5
DEEP WELL INJECTION
SLUDGE HANDLING
GRAVITY THICKENING
FLOTATION THICKENING
AEROBIC DIGESTION
ANAEROBIC DIGESTION
LAGOON & DRYING
DRYING BEDS
LAND DISPOSAL
CENTRIFUGATION
VACUUM FILTRATION
L = 35.7
LANDFILL
INCINERATION
WET OXIDATION
BARGING
HAULING

Where available and applicable, mathematical models have been developed for specific processes. These are shown in Figure 13. The average coefficients for these models are summarized in Table XIII and the ranges of values obtained from 14 different chemical wastes receiving biological treatment are given. A definition of the symbols used in Figure 13 is detailed in Table XIV.

The mathematical models shown in Figure 13 and the average coefficients shown in Table XIII have been used to develop the treatment plant sizes for the cost vs effluent quality study discussed later in this report.

COST FUNCTIONS

The total cost functions and the unit cost functions which were developed are based on data reported for actual organic chemical plants which treat wastewater. The cost data were derived from information reported in the "Industrial Waste Profiles - The Cost of Clean Water," in published and private reports, and from private communications. All the cost data have been adjusted to 1968 costs using the Engineering News Record (ENR) Construction Cost Index.

The total capital cost functions for activated sludge treatment plants are graphically related to wastewater flow in Figures 14 and 15 and to incoming BOD in Figures 16 and 17.

The systems which were considered included pretreatment or primary treatment, the activated sludge aeration basin(s) and equipment, and final clarifier(s). However, in one system sludge treatment was included and the other system included lagooning of the sludge. The data in Figures 14 and 16 are for eight activated sludge plants with sludge treatment and the data for fourteen activated sludge plants without sludge treatment are presented in Figures 15 and 17. There is a better relationship between total capital cost and flow than between cost and BOD for both systems.

A mathematical expression of the relationship between total capital cost and the flow and BOD is presented in Table XV. The constants and exponents which are also reported in Table XV were evaluated by means of a regression analysis of the data presented in Figures 14-17 inclusive. The results of the regression analyses indicate that for the system without sludge treatment the wastewater flow and incoming BOD concentration seem to have an equal effect on the total capital cost. However, in the system with sludge treatment the wastewater flow seems to have a more marked effect on the total capital cost than does the incoming BOD concentration.

The total capital cost function presented in Table XV is applicable only over the range of data used in the regression anal-

TABLE XIII
COEFFICIENTS AND CONSTANTS FOR BIOLOGICAL TREATMENT OF WASTES FROM THE CHEMICAL INDUSTRY

Activated Sludge	Range of Values (1 standard deviation)		Average
k (1/mg-hr)	0.00012	- 0.00076	0.00024
a	0.31	- 0.72	0.52
a'	0.31	- 0.76	0.53
b (day^{-1})	0.02	- 0.18	0.07
b' (day^{-1})	0.10	- 0.24	0.17
θ	1.0	- 1.04	1.03
F (1b BOD/1bMLVSS/day)	0.4	- 0.0	0.5
Aerated Lagoon			
K (day^{-1})	0.5	- 1.0	0.75
X_v (mg/1)	50.	- 150.	100.
θ^v	1.085	- 1.1	
Anaerobic Lagoons			
K (day^{-1})	0.030	- 0.055	0.042
K_e (day^{-1})	0.07	- 0.13	0.10
θ^e	1.08	- 1.09	1.085
Trickling Filter			
$K' = kxA_v^m$	0.24	- 1.25	
n	0.4	- 0.5	
θ	1.035	- 1.08	
Gravity Thickeners			
B	4.	- 16.	
n	0.25	- 1.8	
M.L. (1b/sq ft/day)	4.	- 12	
C_u (percent solids)	3.	- 5.	

*K reaction rate for equation $\frac{S_e}{S_o} = \frac{1}{1+Kt}$ (applicable to single ponds)

K_e reaction rate constant for equation $\frac{S_e}{S_o} = e^{-K_e \Sigma t}$ (applicable to series of ponds)

K' based on loading in MGAD

Vacuum Filtration			
m	0.5	- 0.71	
n	0.5	- 0.70	
s	0.72	- 0.88	
Cake Moisture (% by wt)	72.	- 79.	
Loading Ranges (1b solids/sq ft/hr)	3.	7.	5.
Aerobic Digestion			
Retention time (days)	10.	- 24.	15.
Carbon Adsorption			
1bs COD/1b Carbon	0.3	- 0.6	0.5
Filtration			
gpm/ft^2	5.	- 10.	
Primary Sedimentation			
Overflow rate ($gal/day/ft^2$)	500	1000.	750.
Secondary Sedimentation			
Overflow rate ($gal/day/ft^2$)	500.	700.	600.

TABLE XIV - LIST OF SYMBOLS

X_a, X_d, X_v	Average, degradable fraction, and volatile fraction of the mass of the biological cells (lbs)
x_a, x_d, x_v	Average, degradable, and volatile biological solids concentration in aeration basin (mg/l)
ΔX_v	Cell or sludge yield (lbs/day)
S_a, S_r	Substrate (expressed as BOD or COD) applied or removed (lbs/day)
s_o, s_e	Influent and effluent substrate concentration (mg/l)
K, K_e, K_d	Substrate removal rate coefficients and biological sludge oxidation rate (day^{-1})
K'	Substrate removal rate for trickling filter
k	Substrate removal rate coefficient (liter/mg-hr)
θ	Temperature coefficient for the rate constant k or K
T	Temperature (°C)
a	Fraction of substrate removed, used for cell synthesis
a'	Oxygen utilization coefficient for cell synthesis
b	Cell auto-oxidation rate coefficient (day^{-1})
b'	Oxygen utilization rate for endogenous respiration (day^{-1})
t	Time, retention time or cycle time (minutes, hours or days)
A_v	Specific surface area of volatile media for trickling filters
F	Food to micro-organism ratio (lb BOD/lb MLVSS/day)
V	Volatile fraction of biological sludge
f	Degradable fraction of volatile solids
SS	Suspended Solids (mg/l)
BOD	Biochemical Oxygen Demand, 5 days at 20°C (mg/l)
BOD_u	Biochemical Oxygen Demand, ultimate at 20°C (mg/l)
COD	Chemical Oxygen Demand (mg/l)
TDS	Total Dissolved Solids, inorganic (mg/l)
mg/l	Milligrams per liter
SRT	Solids Retention Time
P_o	Amount of phosphorous in influent (lb)
N_o	Amount of nitrogen in influent (lb)
L	Vacuum Filter Loading (lb per sq ft per hour)
C_u	Underflow concentration of solids from thickener (% solids)
C_o	Overflow concentration from sludge thickener (% solids)
ML	Mass Loading for sludge thickener (lbs per sq ft per hr)
B	Constant for sludge thickener
D	Depth (ft)
P	Vacuum pressure for vacuum filtration (inches Hg)
s	Coefficient of compressibility of filter cake
c	Weight of solids per unit volume of filtrate (gm/ml)
u	Kinematic viscosity of the liquid (centipoise)
R_o	Specific resistance of the filter media (sec^2/gm)
m,n	Exponents, constant for specific type of sludge
F_o	Overflow concentration for flotation process (% solids)
F_u	Underflow concentration for the flotation process (%)
Q	Flow rate (MGD, gpm, etc.)

Figure 14

TOTAL CAPITAL COST RELATIONSHIP OF ACTIVATED SLUDGE PLANTS WITH SLUDGE TREATMENT

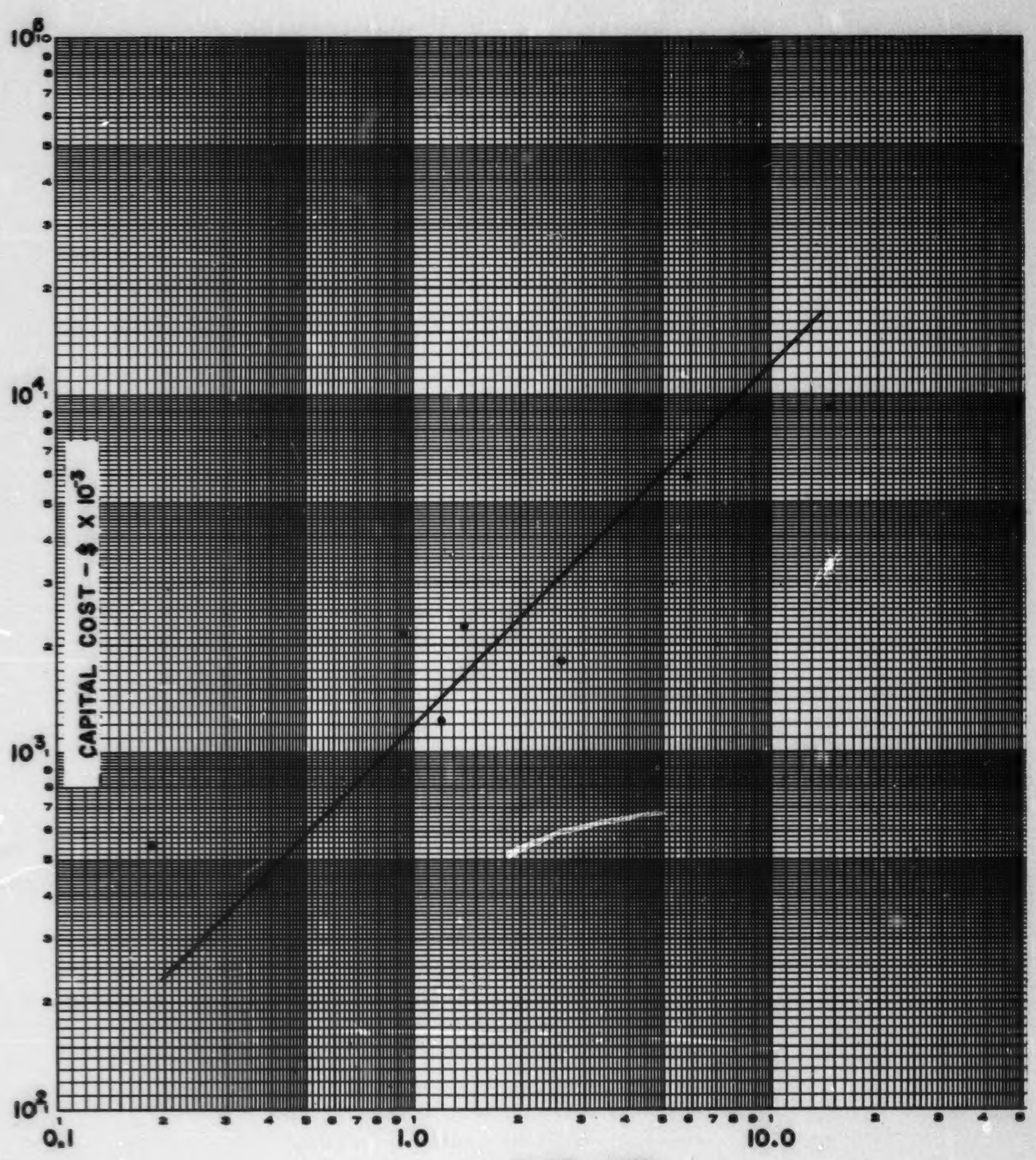


Figure 15

TOTAL CAPITAL COST OF ACTIVATED SLUDGE PLANTS WITHOUT SLUDGE TREATMENT

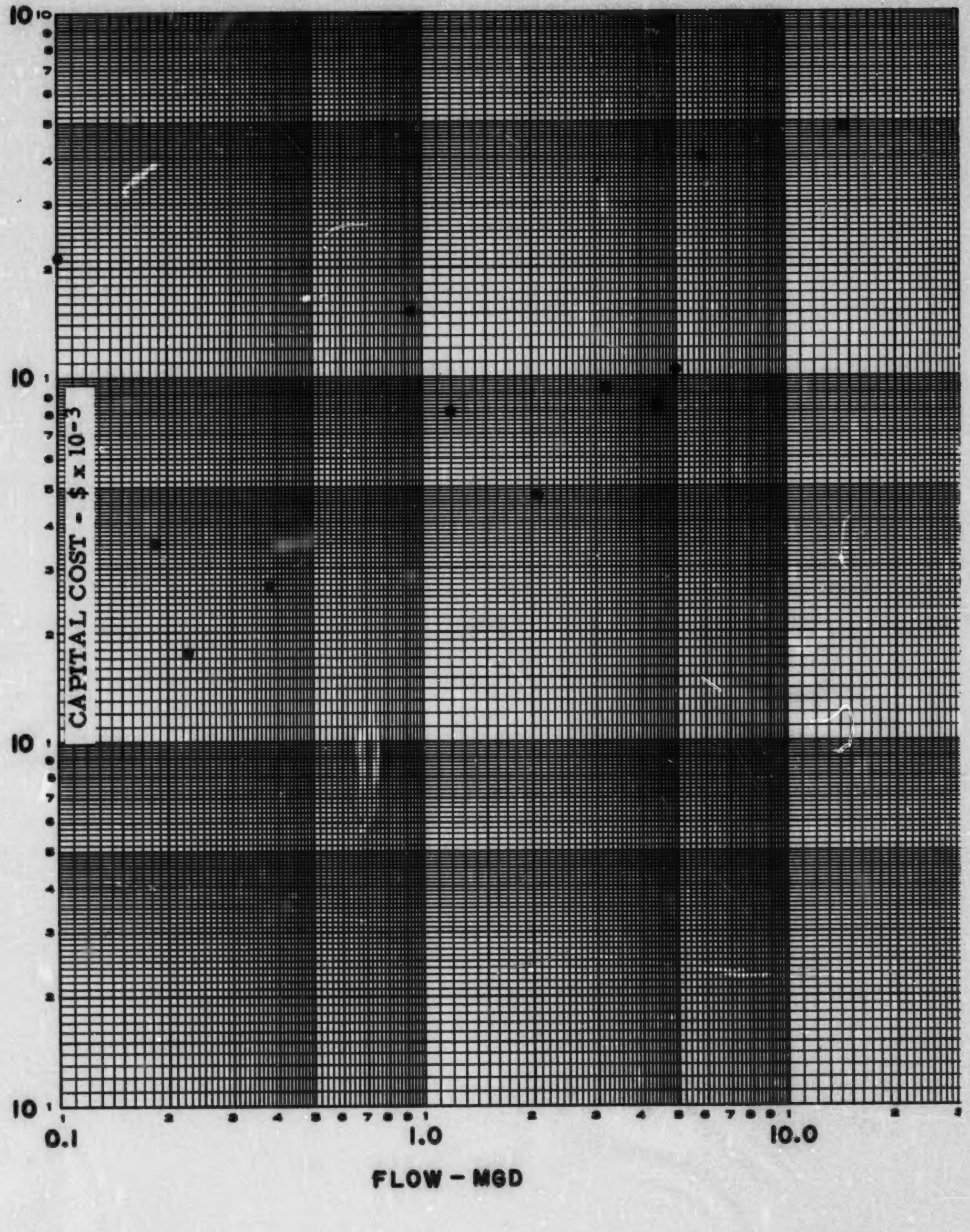


Figure 16

TOTAL CAPITAL COST OF ACTIVATED SLUDGE WITH SLUDGE TREATMENT

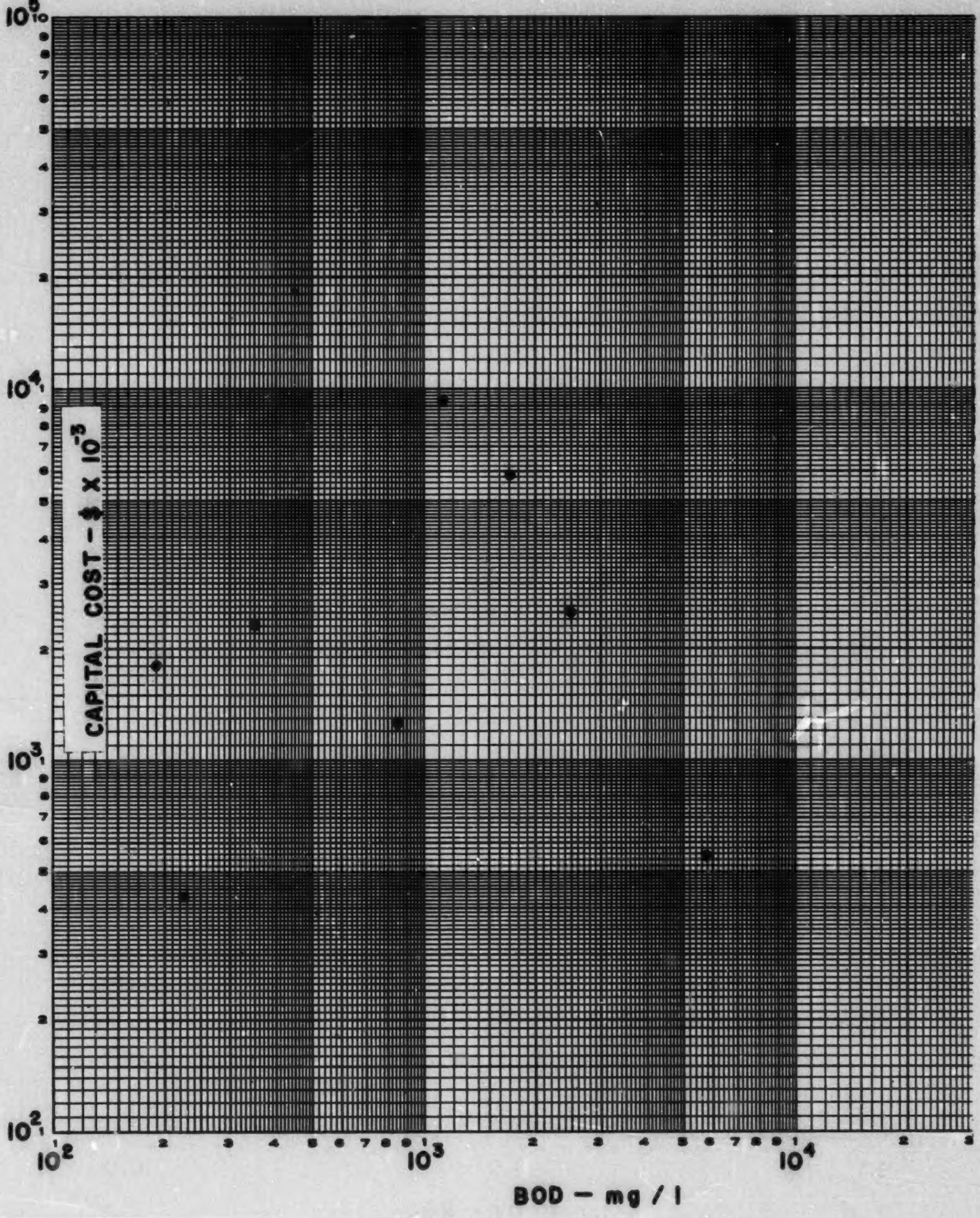
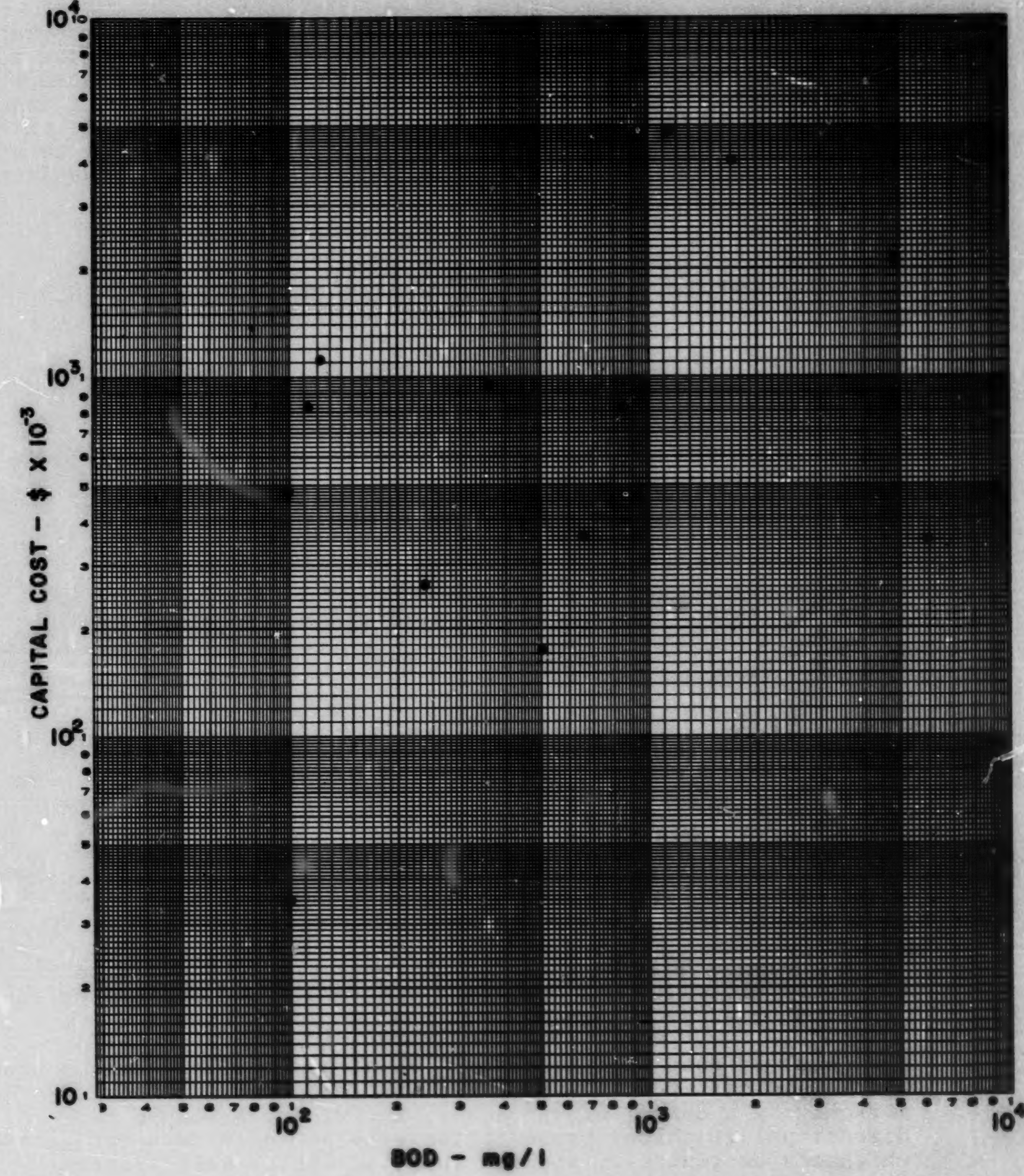


Figure 17

TOTAL CAPITAL COST OF
ACTIVATED SLUDGE PLANTS WITHOUT SLUDGE TREATMENT



yses. The flow range over which the relationship can be applied is 30,000 gallons per day to 15 million gallons per day and the BOD range is 150 mg/l to 6000 mg/l.

The unit cost functions for the various unit processes are graphically presented in Appendix D. The treatment processes and cost function relationship, for which data are available are summarized in Table XVI. The range of applicability of the unit cost function for each of the processes presented are illustrated by the extent of the curve(s) in Appendix D. One should be careful not to attempt to apply these unit cost functions beyond the range of the data presented.

TABLE XV

MATHEMATICAL MODEL OF WASTE TREATMENT COSTS, USING THE COST OF EXISTING FACILITIES

$$C = K\,Q^m\,S_o^n$$

where C - Capital cost in $1,000 (1968 replacement value)
K = Constant
Q = Flow in MGD
S_o = BOD of waste in mg/l

	K	m	n
Activated sludge without sludge treatment	62.0	0.44	0.41
90% confidence limits	14.1-270	±0.14	±0.23
Activated sludge with sludge treatment	433	0.71	0.17
90% confidence limits	85-2200	±0.20	±0.23

The total capital cost for a particular treatment system may be calculated by adding the unit cost of each process included in the system and to this total add 35 percent to cover the costs of piping, pumping, engineering and other contingencies. The percentage was derived by comparing the total reported capital cost of an existing plant with the total capital cost which was calculated by adding the unit costs of each unit process.

The difference between these total costs was considered to include the miscellaneous cost mentioned above and was expressed in terms of a percentage of the total capital cost.

The costs of deep well disposal present particularly unique problems. The cost function for deep well disposal is affected markedly by a number of variables, therefore, a simple two-dimensional graphical presentation will not provide a relationship which can be generally applied to all disposal well systems. The variables which are significant include:

a. Flow rate
b. Required surface pretreatment
c. Diameter and number of the well and
d. Operating casing head pressure

Geological characteristics including type of formation, permeability and porosity are other factors which can affect the total capital cost.

The operating costs for disposal wells are primarily a function of the operating well head pressure which in turn is affected by the formation properties. The flow rate is related to some extent to the operating pressure especially in the case where the friction loss is high. The friction loss can be significant in a multiple well system in which a distribution system is employed. The cost of surface pretreatment will also add to the operating costs.

TABLE XVI

SUMMARY OF BASES FOR UNIT COST FUNCTIONS

Pre or Primary Treatment	
Equalization	Cost vs. volume (Gal)
Neutralization	Cost vs. flow rate (MGD)
Oil Separation	Cost/MGD vs. flow Rate (MGD)
Sedimentation	Cost vs. Surface Area (Sq Ft)
Biological Treatment	
Lagoons	Cost vs. Surface Area (Acre)
Aerated Lagoons	Cost vs. volume (MG)
Activated Sludge	
Aeration basin	Cost vs. volume (MG)
Final Clarifier	Cost vs. Surface Area (Sq Ft)
Tertiary Treatment	
Filtration	Cost vs. flow rate (MGD)
Ion Exchange	Cost vs. flow rate (MGD)
Adsorption (carbon)	Cost vs. flow rate (MGD)
Sludge Handling and Disposal	
Total sludge disposal	Cost vs. flow rate (MGD)
Thickening	Cost vs. volume of thickener (gal)
Flotation thickening	Cost/MGD vs. flow rate MGD
Vacuum Filtration	Cost vs. area of filter (Sq Ft)
Ultimate Disposal	
Deep Well Injection	Cost vs. flow rate (MGD)

X. COST VS EFFLUENT QUALITY RELATIONSHIPS

In order to establish a realistic basis for establishing treatment plant design criteria, the data of the 53 plants surveyed were portrayed in terms of statistical probabilities of COD, BOD, and suspended solids concentrations as shown in Figures 18 and 19 and in a graphical illustration of wastewater flow and BOD concentration as shown in Figure 20. These data were used to construct the twenty likely design combinations given in Table XVII.

TABLE XVII

PLANT SIZE AND WASTEWATER CHARACTERISTICS - BASIS FOR DESIGN

Combination	Plant Design Flow (mgd)	BOD (mg/1)	COD (mg/1)	SS (mg/1)
1	10.0	500	1200	100
2	10.0	500	1200	500
3	10.0	200	550	100
4	10.0	200	550	500
5	5.0	2000	5000	100
6	5.0	2000	5000	500
7	5.0	500	1200	100
8	5.0	500	1200	500
9	1.0	3000	8000	100
10	1.0	3000	8000	500
11	1.0	1000	3000	100
12	1.0	1000	3000	500
13	1.0	500	1200	100
14	1.0	500	1200	500
15	0.5	3000	8000	100
16	0.5	3000	8000	500
17	0.5	1000	3000	100
18	0.5	1000	3000	500
19	0.5	500	1200	100
20	0.5	500	1200	500

The cost vs effluent quality relationships have been developed using BOD, COD, suspended solids and total dissolved inorganic solids as quality parameters. Nitrogen and phosphorous have not been included since in the majority of cases, these are present in insufficient concentrations and must be added as nutrient supplements. Constituents such as color represent specific cases and have, therefore, not been included in the general correlations. The range of treatment plant sizes and wastewater composition selected has been discussed and is based upon current production in the chemical industry.

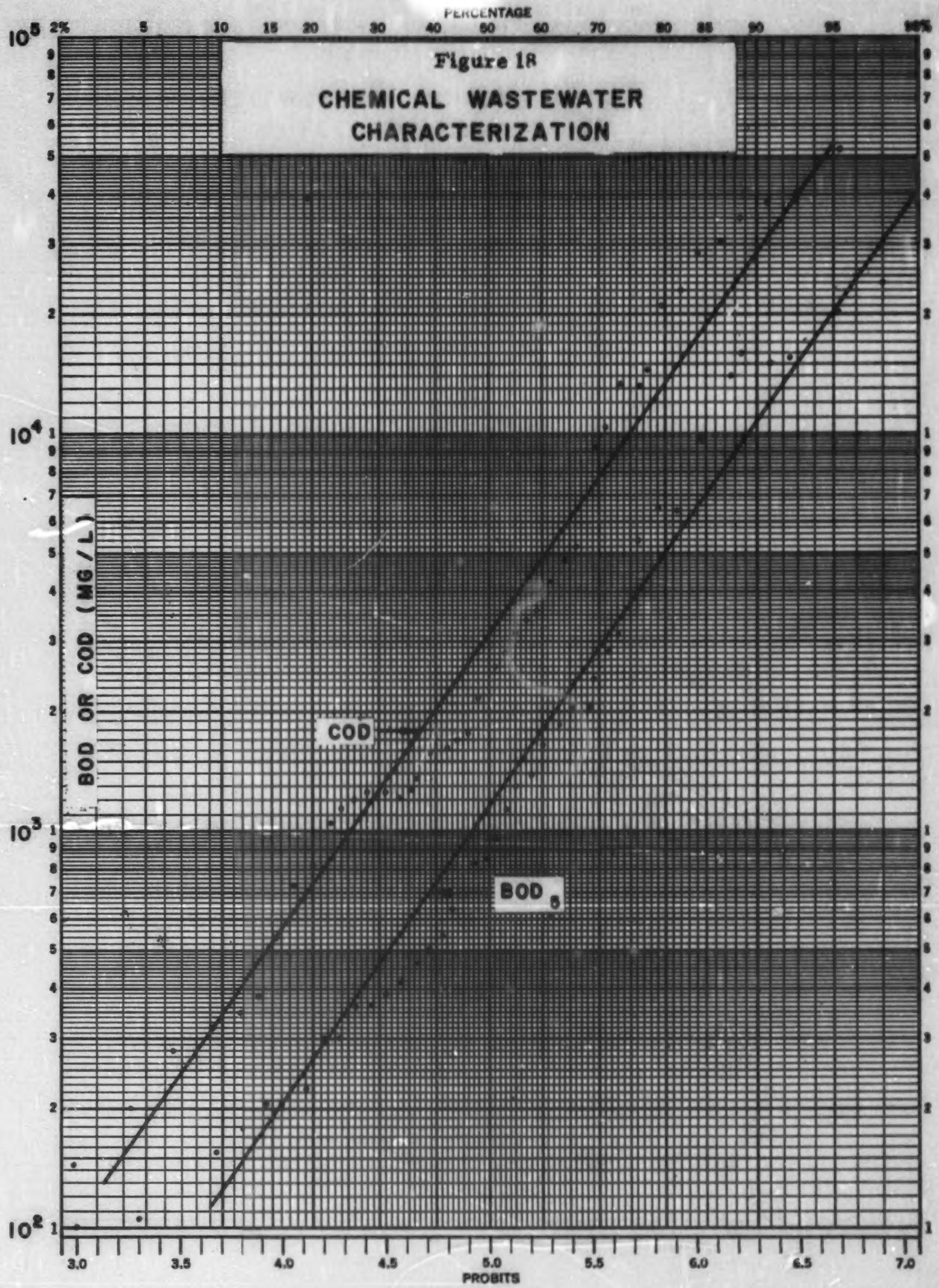


Figure 18

CHEMICAL WASTEWATER CHARACTERIZATION

Figure 19

CHEMICAL WASTEWATER CHARACTERIZATION

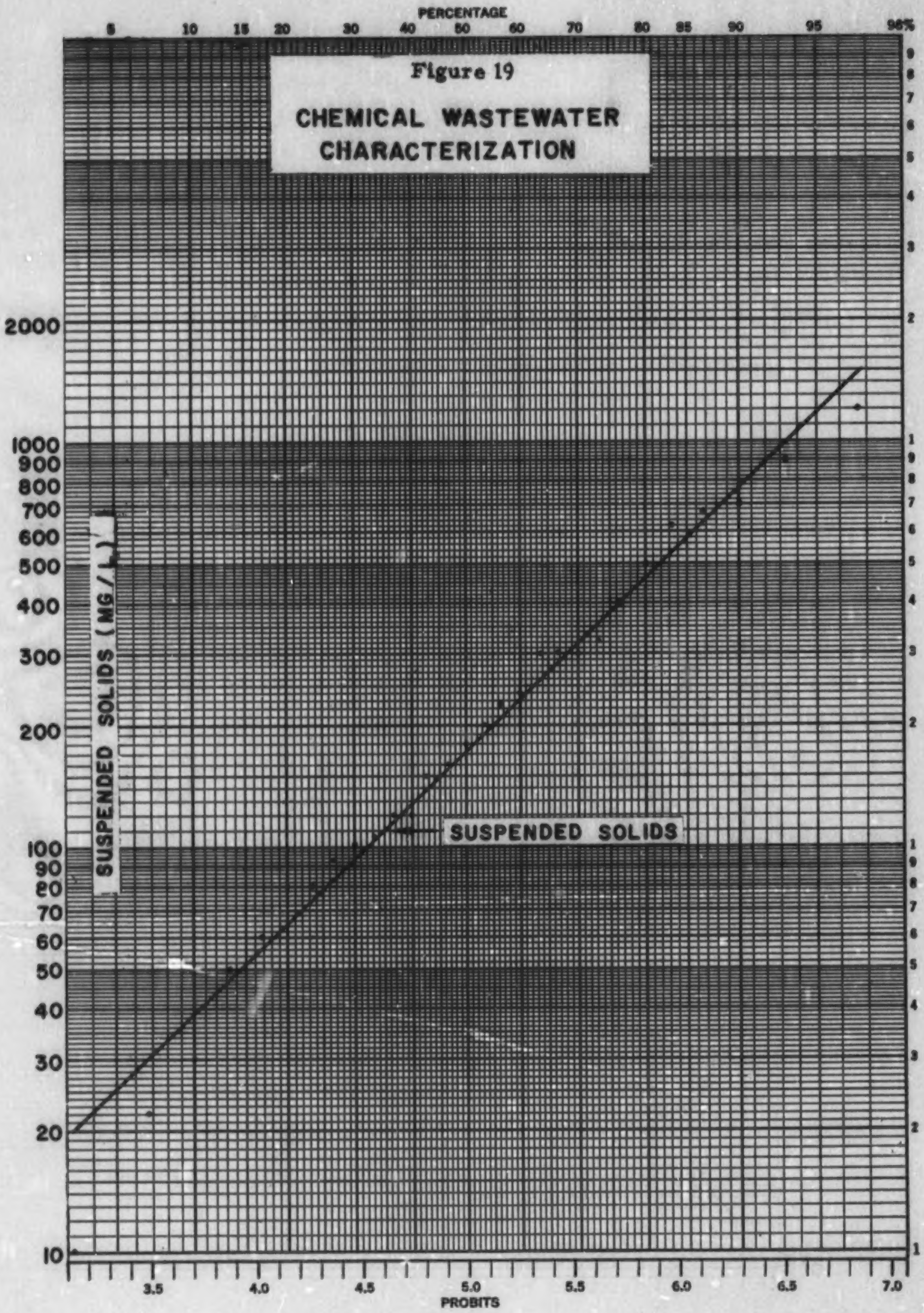
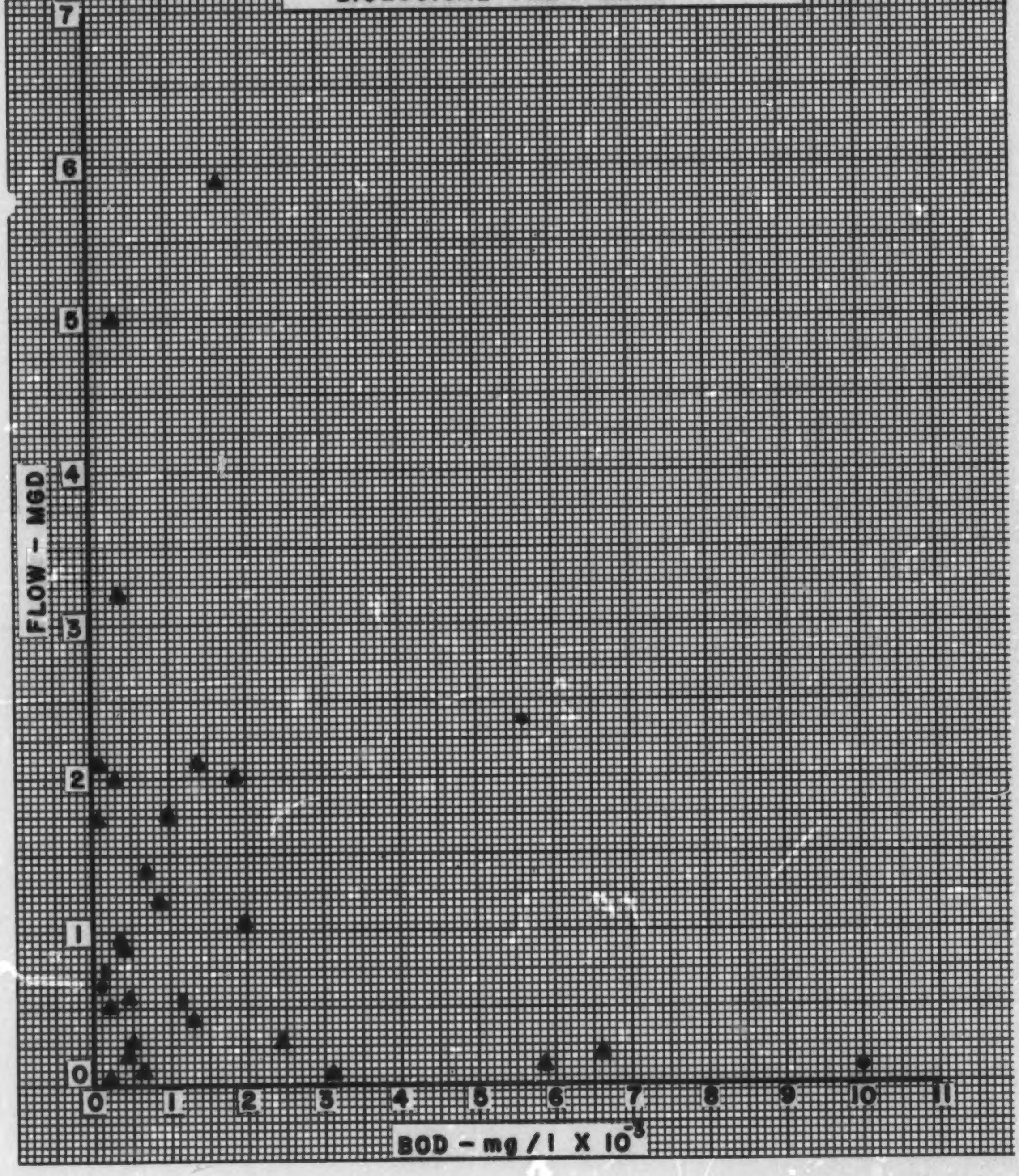


Figure 20

FLOW – BOD RELATIONSHIP FOR EXISTING CHEMICAL WASTEWATER TREATMENT PLANTS



The generalized wastewater treatment processes and alternates are shown in Figure 21. This flow sheet was selected as illustrative of common practice in wastewater treatment plants in the organic chemical industry today and according to projections of what might be required in the near future.

Design Bases For The Process Calculations

1. Sedimentation

Sedimentation is provided when the suspended solids concentration exceeded 125 mg/l. An overflow rate of 750 gpd/ft^2 is used to effect a suspended solids removal of 65%. The percent removal of BOD and COD in sedimentation has been taken as 10% for each.

2. Anaerobic Lagoon

This process is used when the BOD of the wastes exceeds 500 mg/l and it is not preceded by sedimentation. The obtainable effluent BOD and SS concentrations are 200 mg/l and 50 mg/l respectively. Reaction rate constant K (200°C) was taken at 0.42 and the basin volume was computed from the relationship between the effluent BOD and reaction rate.

$$\frac{Se}{So} = \frac{1}{1 + Kt}$$

The effluent COD was computed from the relationship $COD_{OUT} = COD_{IN} - BOD_{removed}/0.75$

3. Aerated Lagoon

Sedimentation is not provided preceding aerated lagoon process. A reaction rate constant of 0.75 (K at 20°C) has been taken and the basin volume is computed from the relationship between effluent BOD and reaction rate constant. The effluent BOD and SS solids are expected to be 100 mg/l each.

4. Activated Sludge

This process is preceded by sedimentation. A reaction rate (k at 20°C) of 0.00024 1/mgVSS-hr and the MLVSS concentration of 2500 mg/l have been taken. Sludge synthesis coefficient and the endogenous respiration rate are taken at 0.52 and 0.07 respectively for the purpose of excess sludge computations. 80% of the excess sludge is assumed to be volatile. Also 80% of the suspended solids entering the activated sludge process is assumed to form an excess sludge. A typical overflow rate of 600 gpd/ft^2 is taken for final clarification. The effluent BOD and SS of this process are expected to be 25 and 20 mg/l respectively.

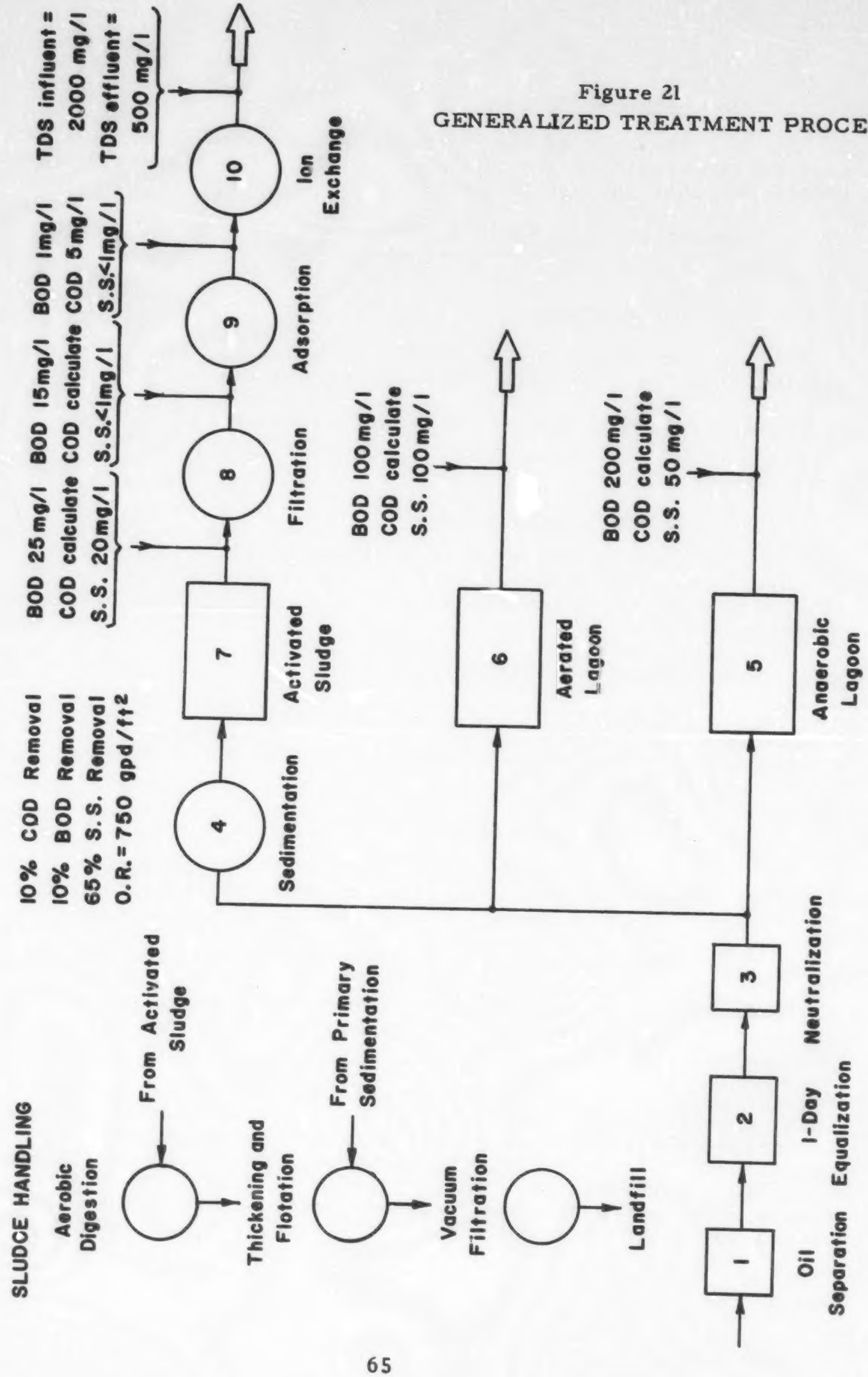

SLUDGE HANDLING
Aerobic Digestion
From Activated Sludge
Thickening and Flotation
From Primary Sedimentation
Vacuum Filtration
Landfill
1
Oil Separation
2
1-Day Equalization
3
Neutralization
4
Sedimentation
10% COD Removal
10% BOD Removal
65% S.S. Removal
O.R. = 750 gpd/ft2
7
Activated Sludge
BOD 25 mg/l
COD calculate
S.S. 20 mg/l
8
Filtration
BOD 15 mg/l
COD calculate
S.S.<1 mg/l
9
Adsorption
BOD 1 mg/l
COD 5 mg/l
S.S.<1 mg/l
10
Ion Exchange
TDS influent = 2000 mg/l
TDS effluent = 500 mg/l
6
Aerated Lagoon
BOD 100 mg/l
COD calculate
S.S. 100 mg/l
5
Anaerobic Lagoon
BOD 200 mg/l
COD calculate
S.S. 50 mg/l

Figure 21
GENERALIZED TREATMENT PROCESSES

5. Adsorption

The cost of this process is computed from the cost curves available for municipal waste. The flows are corrected for this purpose as follows:

$$\text{Corrected flow} - \frac{\text{MGD X COD}_{\text{IND}}}{\text{COD}_{\text{MUN}}} \times 0.75$$

6. Ion Exchange

The flows are corrected as below to obtain the cost figures from the cost curve of domestic waste:

$$\text{Corrected Flow} = \frac{\text{MGD total Dissolved Solids removed}}{350} \times 0.75$$

7. Aerobic Digestion

Only excess activated sludge is treated in this process. The feed concentration of the sludge is taken at 1%. Also with a 15 day detention period, 50% reduction of VSS is expected.

8. Flotation Thickening

The primary sludge and the aerobically digested excess activated sludge are thickened by flotation. Flotation area is estimated at 4 lbs/ft^2/hr. The effluent suspended solids are taken as 30 mg/l.

9. Vacuum Filtration

The thickened sludge is filtered to produce filter cakes at high solids concentration and the filter area is estimated at 8 lbs/ft^2/day.

The capital costs were developed from the sum of the unit process costs plus 35 percent to include the cost of engineering, miscellaneous piping and other appertances and are related to effluent quality in Figures 22-41 for the various size selections.

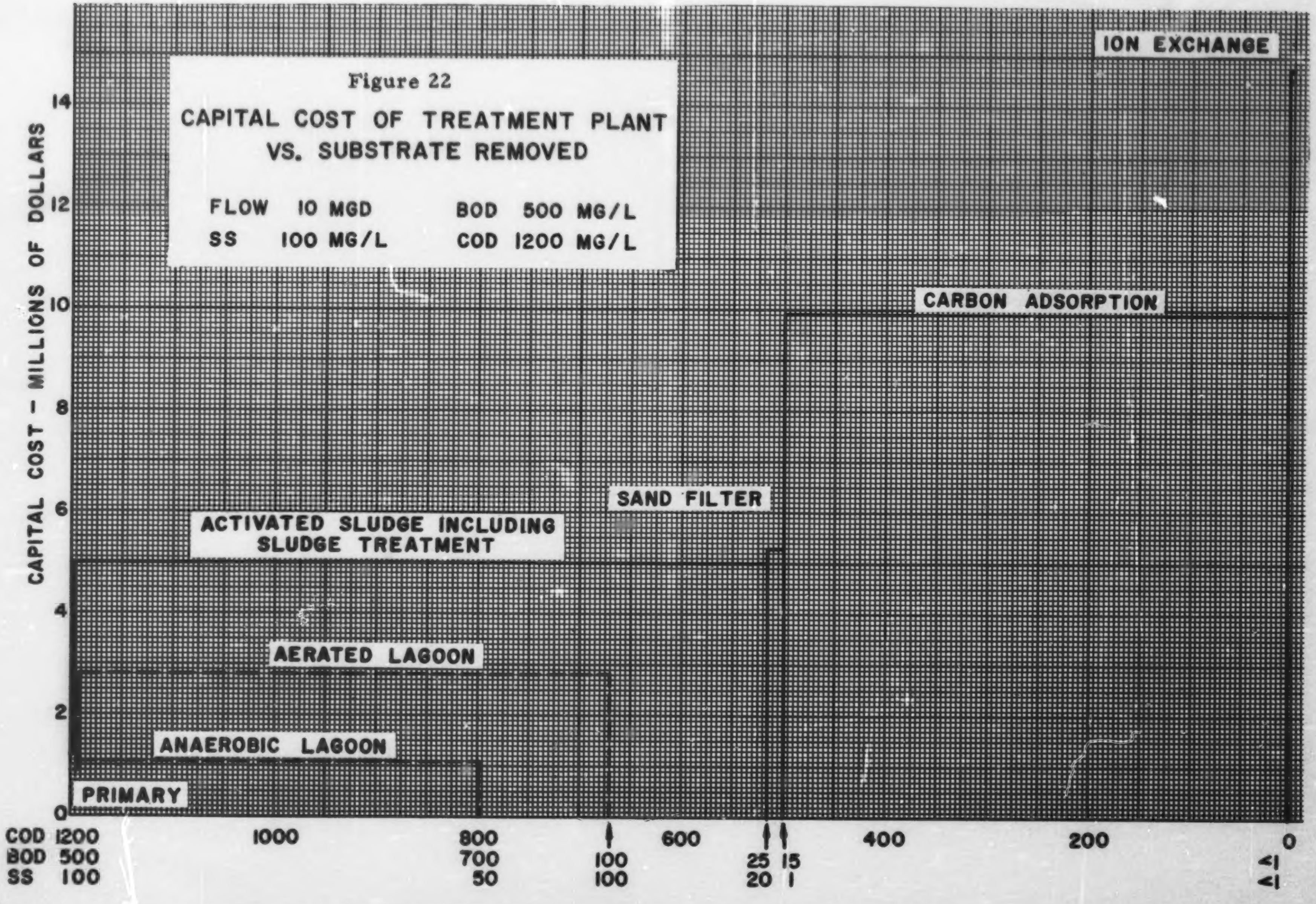
For the purpose of these cost determinations, it was assumed that every selected combination of flow and wastewater characteristics will receive identical treatment, except where impracticable. For example, all waste will pass through the oil separator, neutralization tank, equalization tank (except when followed by lagoons), primary sedimentation (except when suspended solid concentrations are less than 175 mg/l), activated sludge, sand filtration, carbon adsorption, and ion exchange. The excess activated sludge is aerobically digested, mixed with the primary sludge when applicable, and subsequently thickened and vacuum filtered. The cost of sludge treatment, which does not include incineration, barging, or hauling, is included in the cost of the activated sludge unit.

All costs are cumulative as the degree of treatment increases, except that the cost determination of aerated and anaerobic lagoons terminate as shown on the graphs. These unit processes will not be used when tertiary treatment is desired.

Figure 22

CAPITAL COST OF TREATMENT PLANT VS. SUBSTRATE REMOVED

FLOW 10 MGD BOD 500 MG/L
SS 100 MG/L COD 1200 MG/L



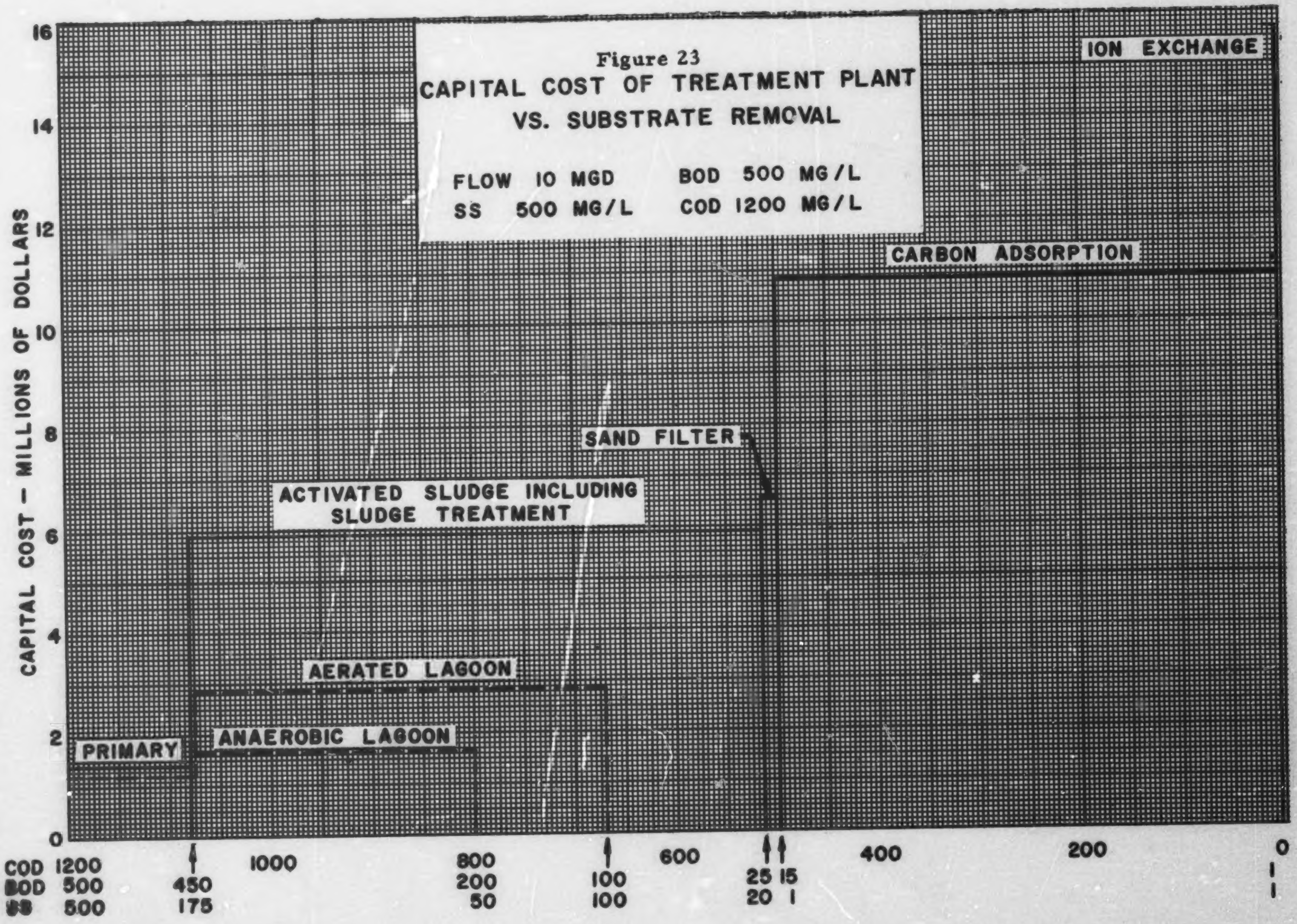


Figure 23
CAPITAL COST OF TREATMENT PLANT VS. SUBSTRATE REMOVAL

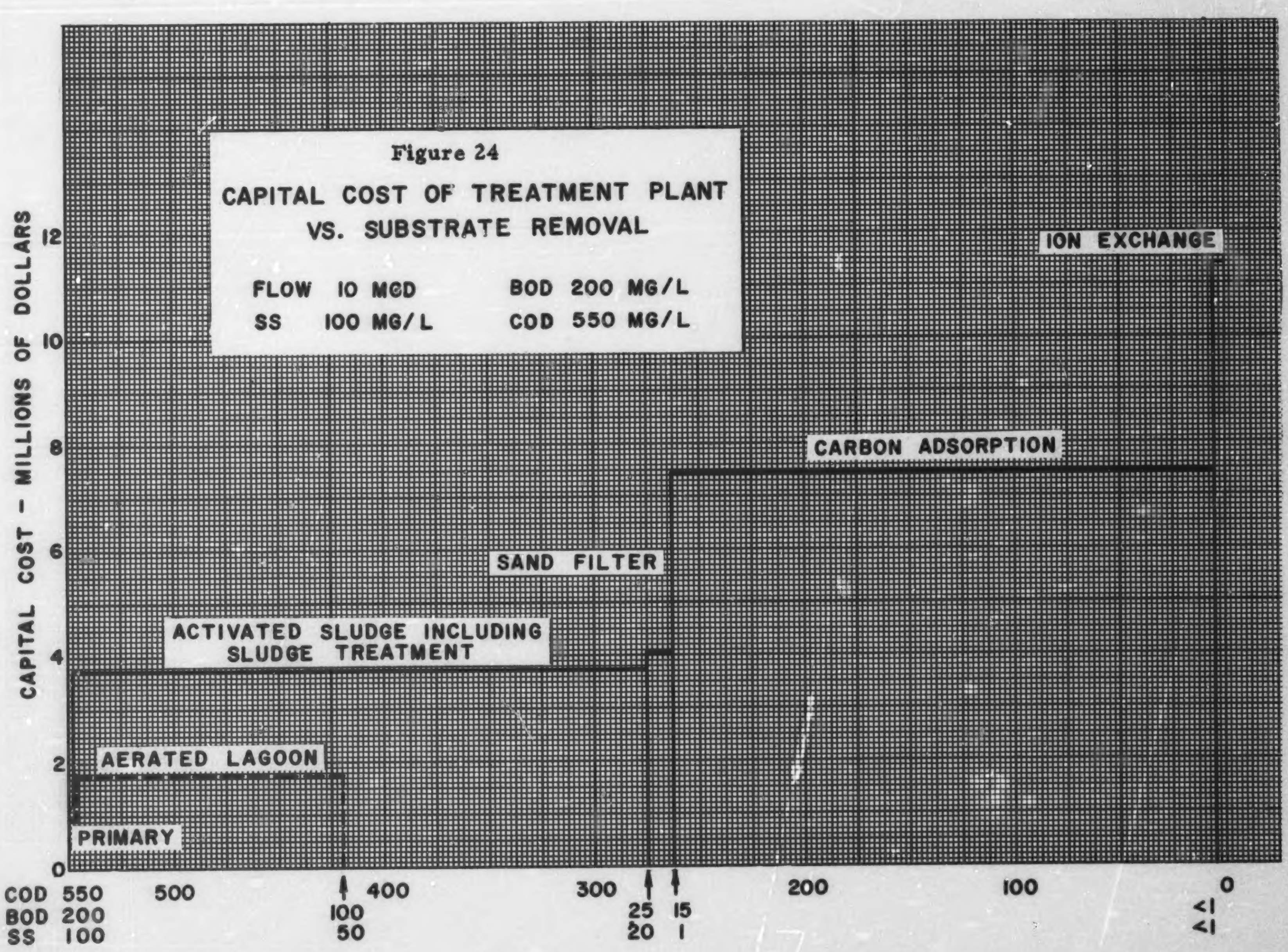


Figure 24

CAPITAL COST OF TREATMENT PLANT VS. SUBSTRATE REMOVAL

FLOW 10 MGD BOD 200 MG/L
SS 100 MG/L COD 550 MG/L

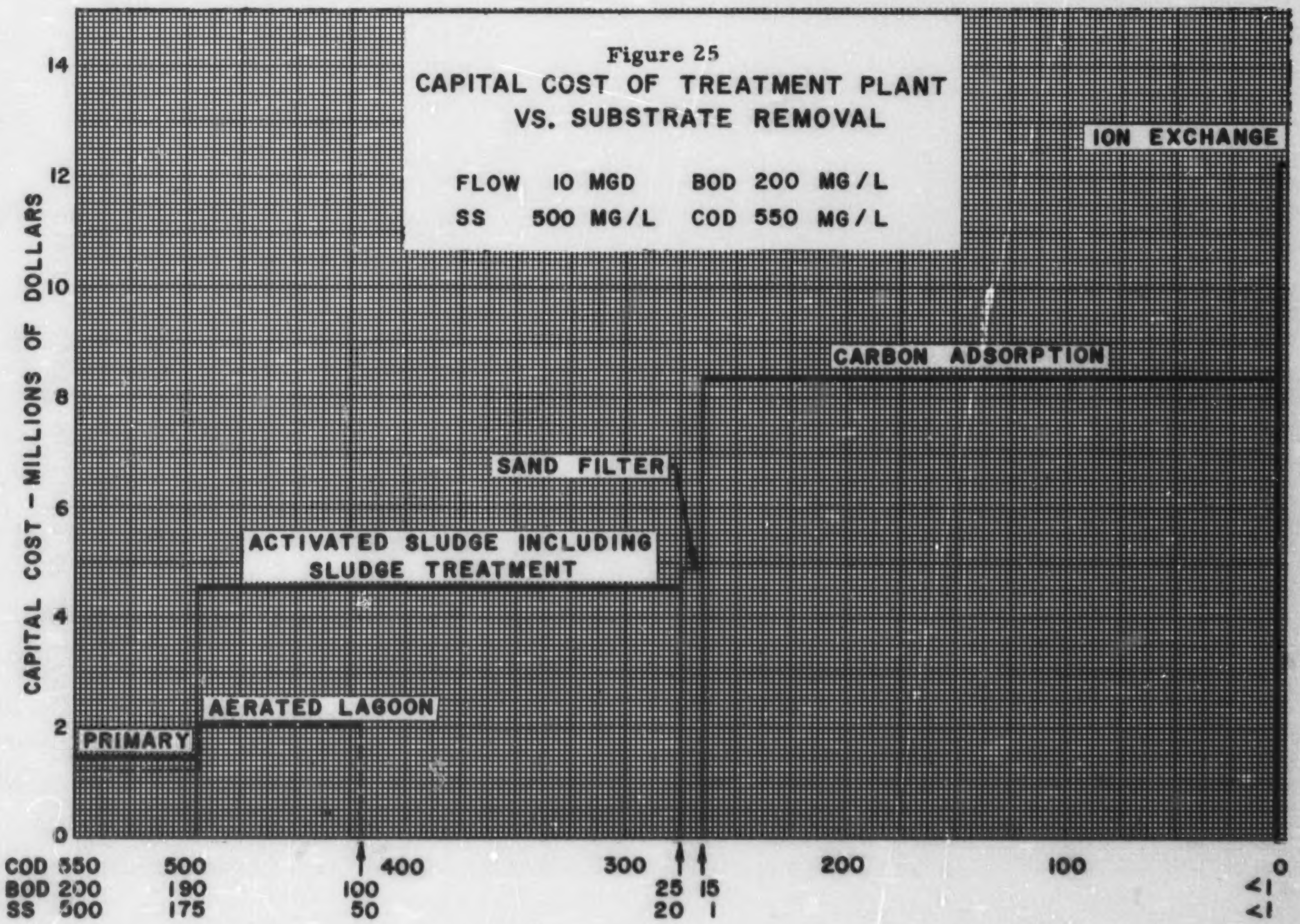


Figure 25
CAPITAL COST OF TREATMENT PLANT VS. SUBSTRATE REMOVAL

FLOW 10 MGD BOD 200 MG/L
SS 500 MG/L COD 550 MG/L

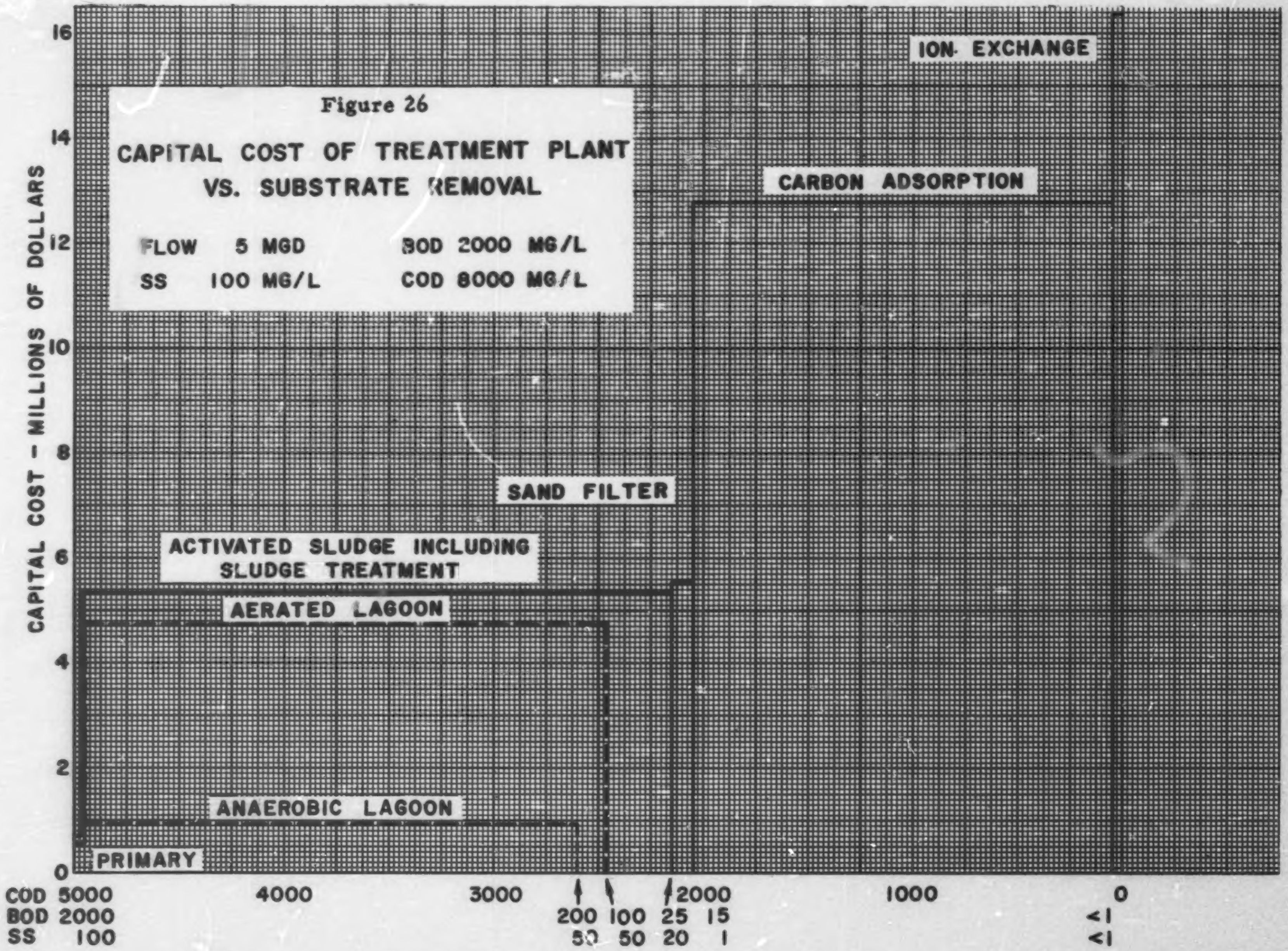


Figure 26

CAPITAL COST OF TREATMENT PLANT VS. SUBSTRATE REMOVAL

FLOW 5 MGD   BOD 2000 MG/L
SS 100 MG/L   COD 8000 MG/L

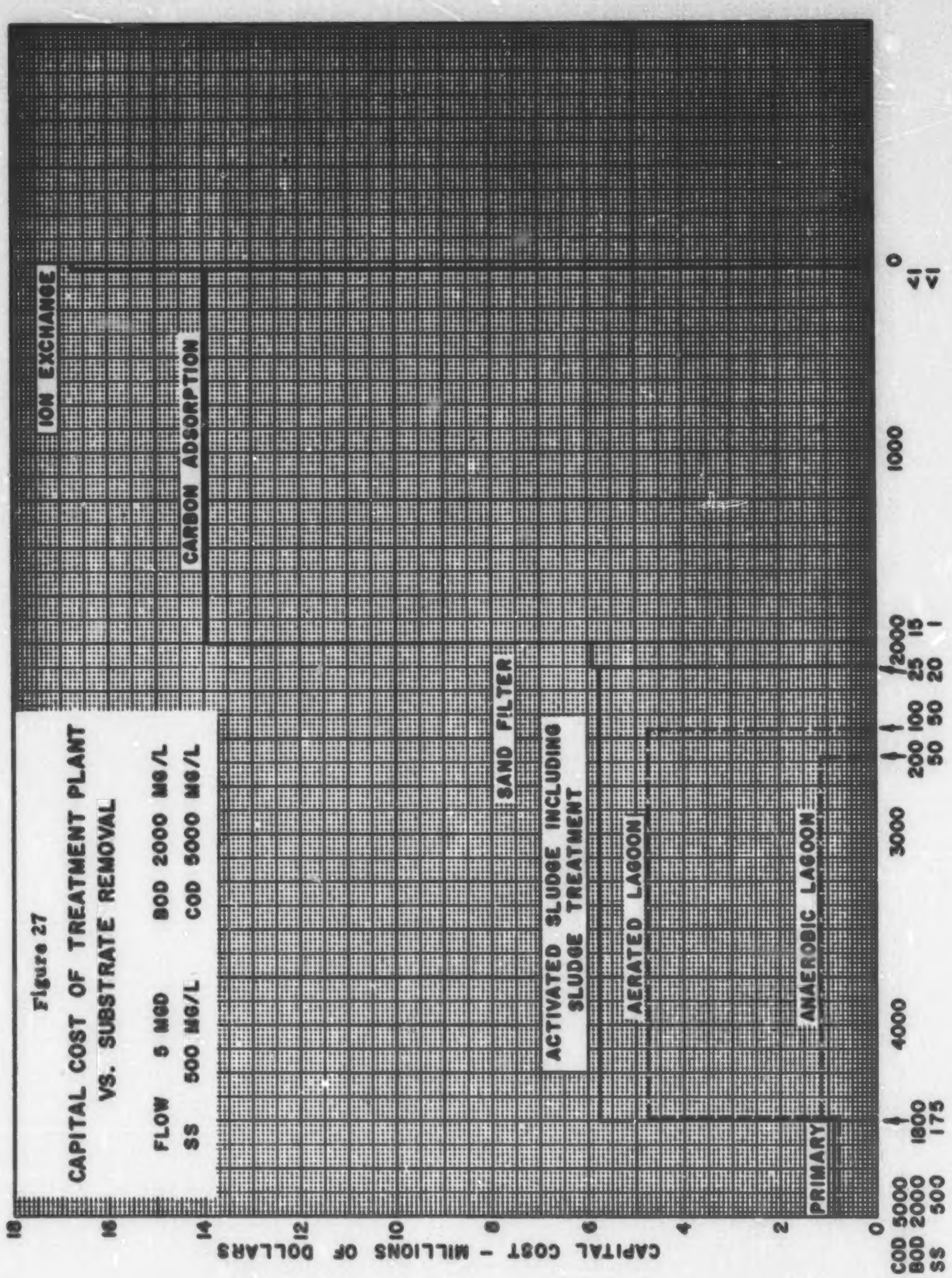


Figure 27

CAPITAL COST OF TREATMENT PLANT VS. SUBSTRATE REMOVAL

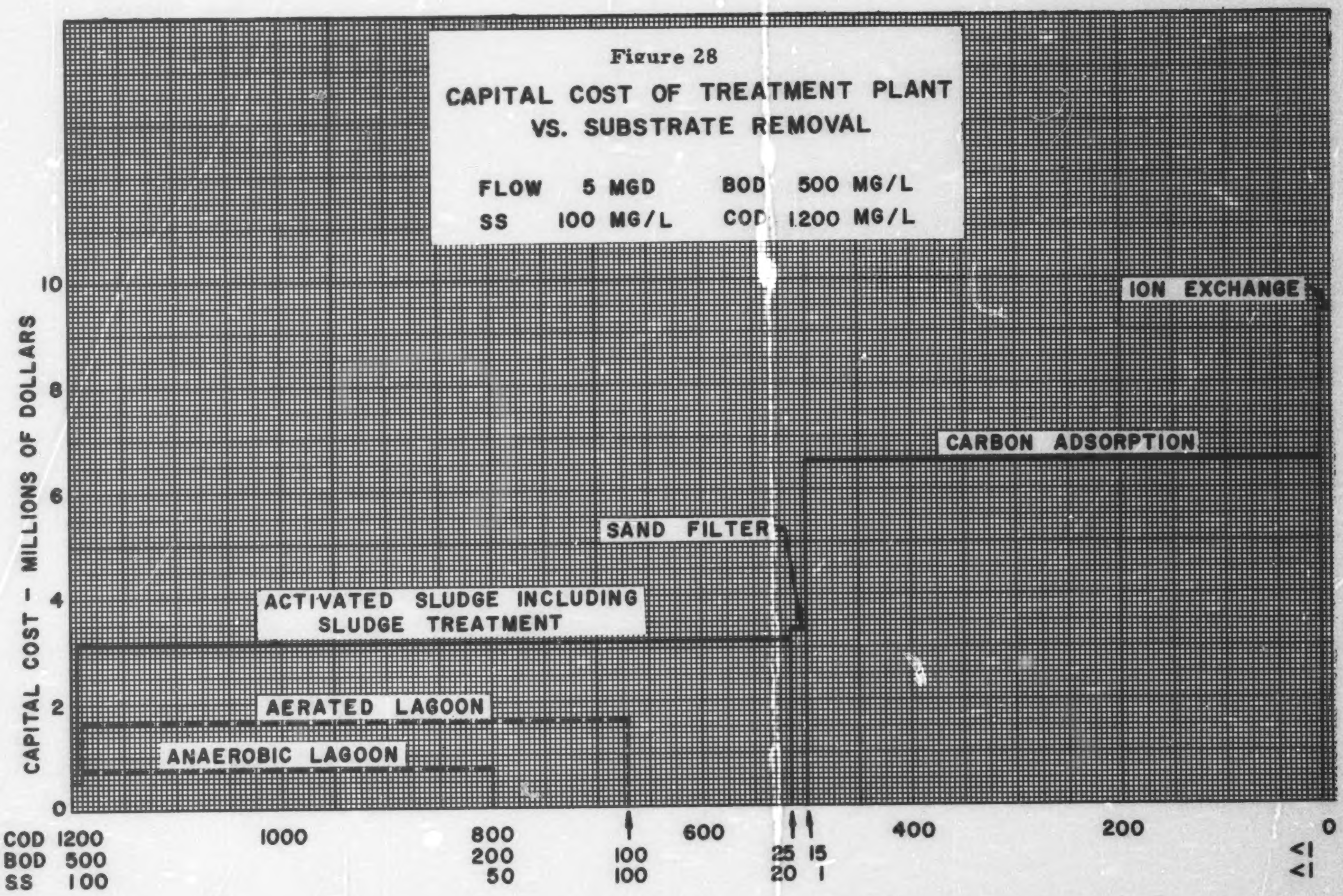


Figure 28

CAPITAL COST OF TREATMENT PLANT VS. SUBSTRATE REMOVAL

FLOW 5 MGD BOD 500 MG/L
SS 100 MG/L COD 1200 MG/L

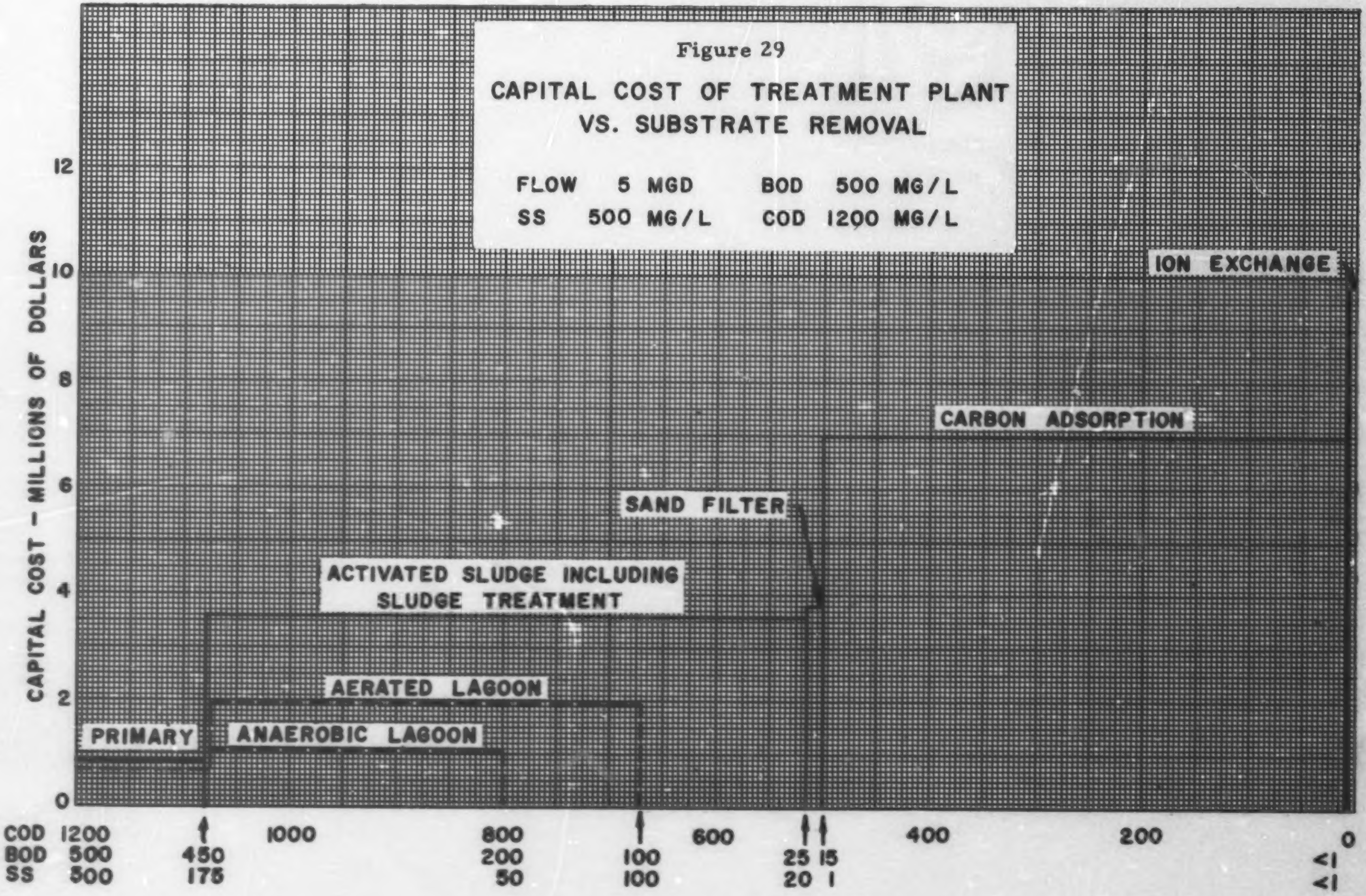


Figure 29

CAPITAL COST OF TREATMENT PLANT VS. SUBSTRATE REMOVAL

FLOW 5 MGD BOD 500 MG/L
SS 500 MG/L COD 1200 MG/L

Figure 30

CAPITAL COST OF TREATMENT PLANT
VS. SUBSTRATE REMOVAL

FLOW 1 MGD BOD 3000 MG/L
SS 100 MG/L COD 8000 MG/L

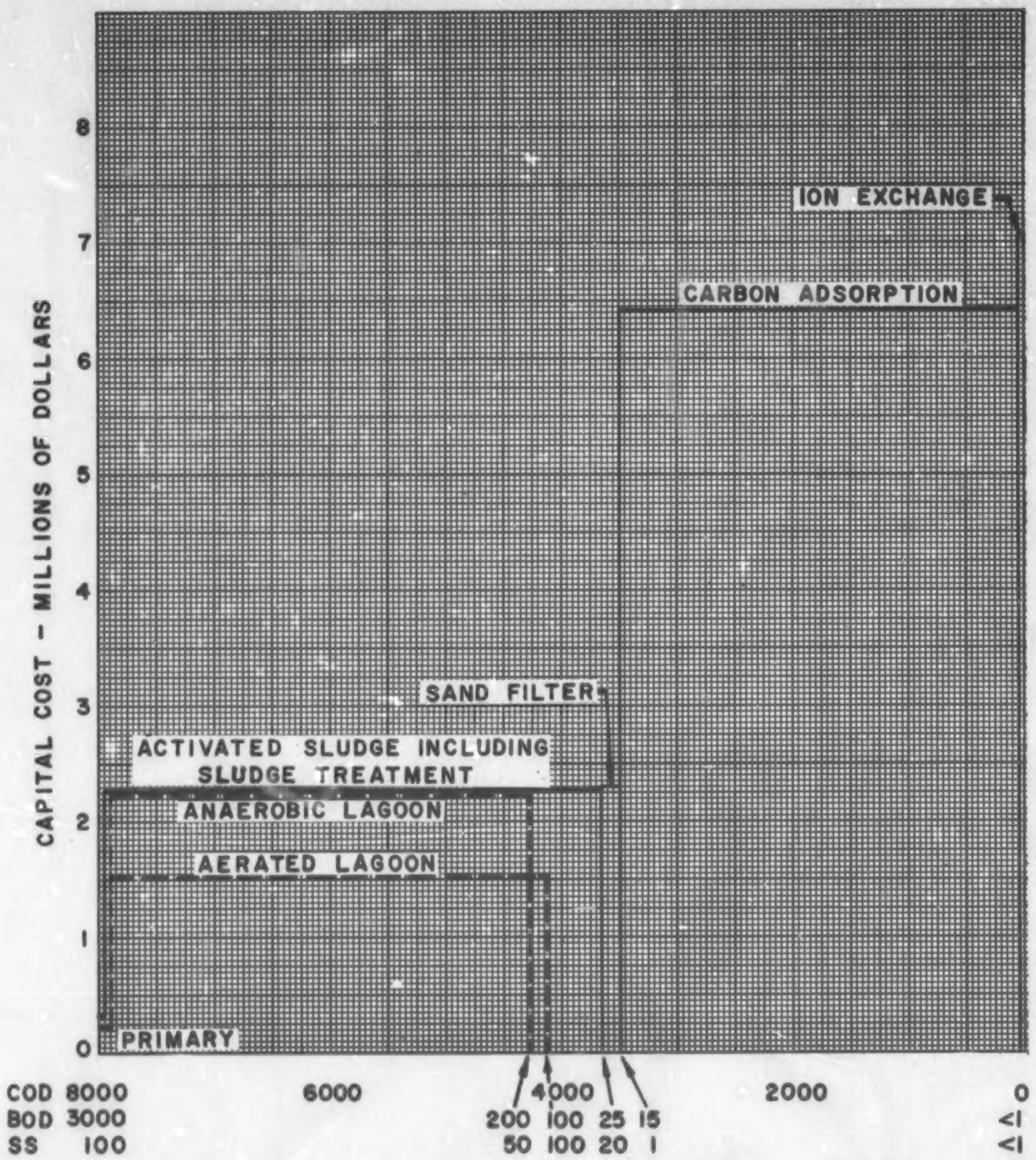


Figure 31

CAPITAL COST OF TREATMENT PLANT
VS. SUBSTRATE REMOVAL

FLOW 1 MGD BOD 3000 MG/L
SS 500 MG/L COD 8000 MG/L

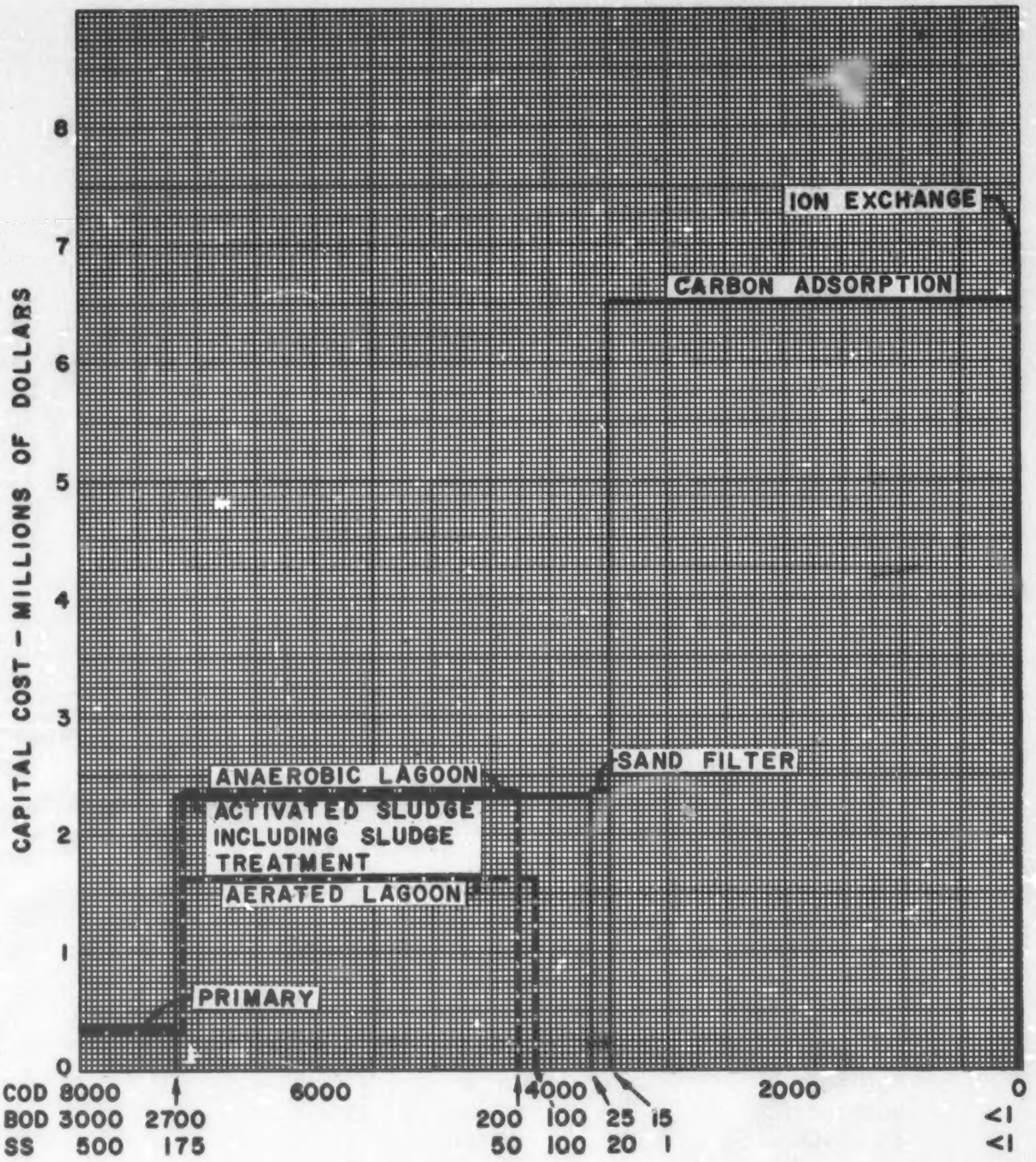


Figure 32

CAPITAL COST OF TREATMENT PLANT
VS, SUBSTRATE REMOVAL

FLOW 1 MGD BOD 3000 MG/L
SS 100 MG/L COD 1000 MG/L

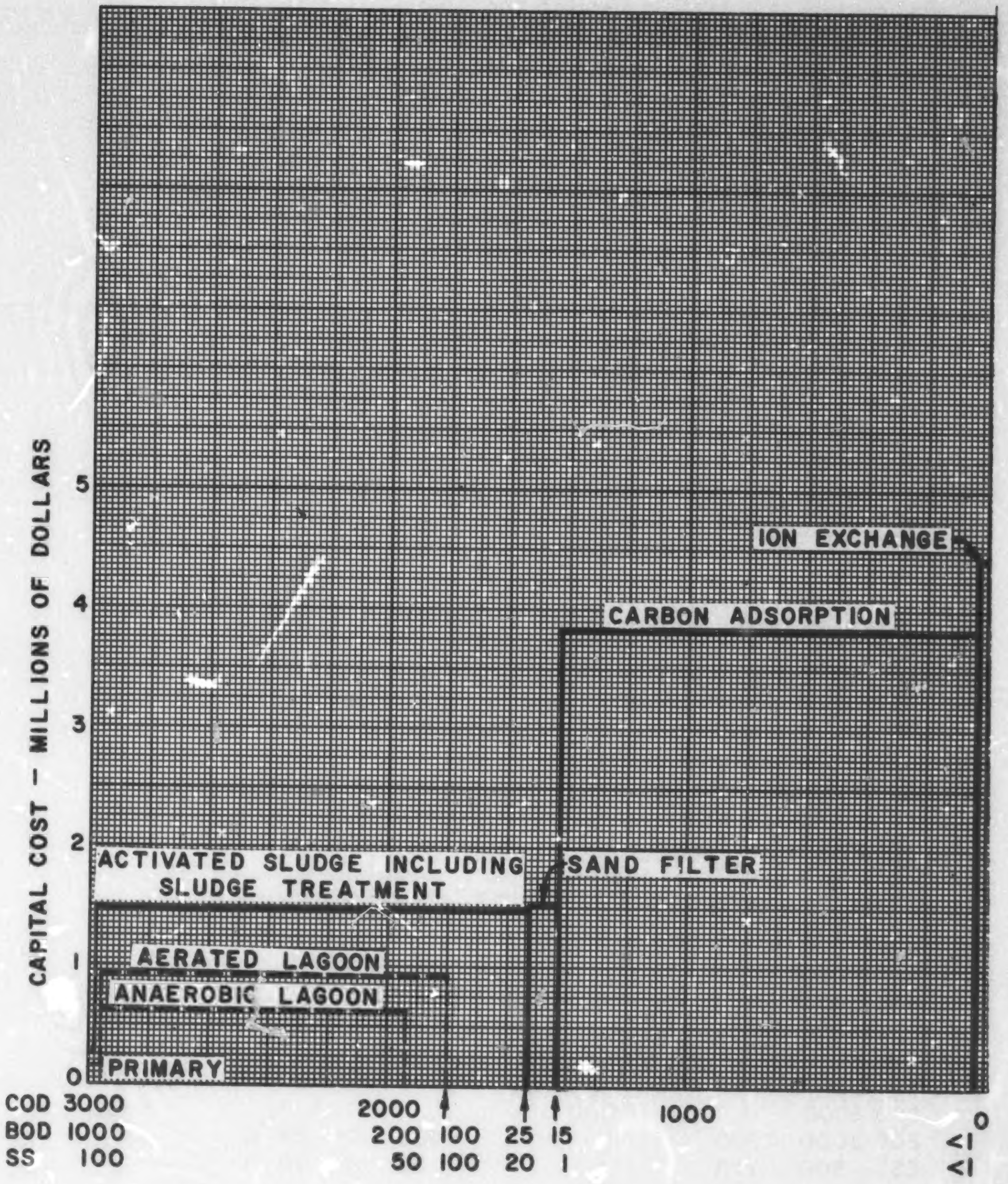


Figure 33

CAPITAL COST OF TREATMENT PLANT VS. SUBSTRATE REMOVAL

FLOW 1 MGD BOD 1000 MG/L
SS 500 MG/L COD 3000 MG/L

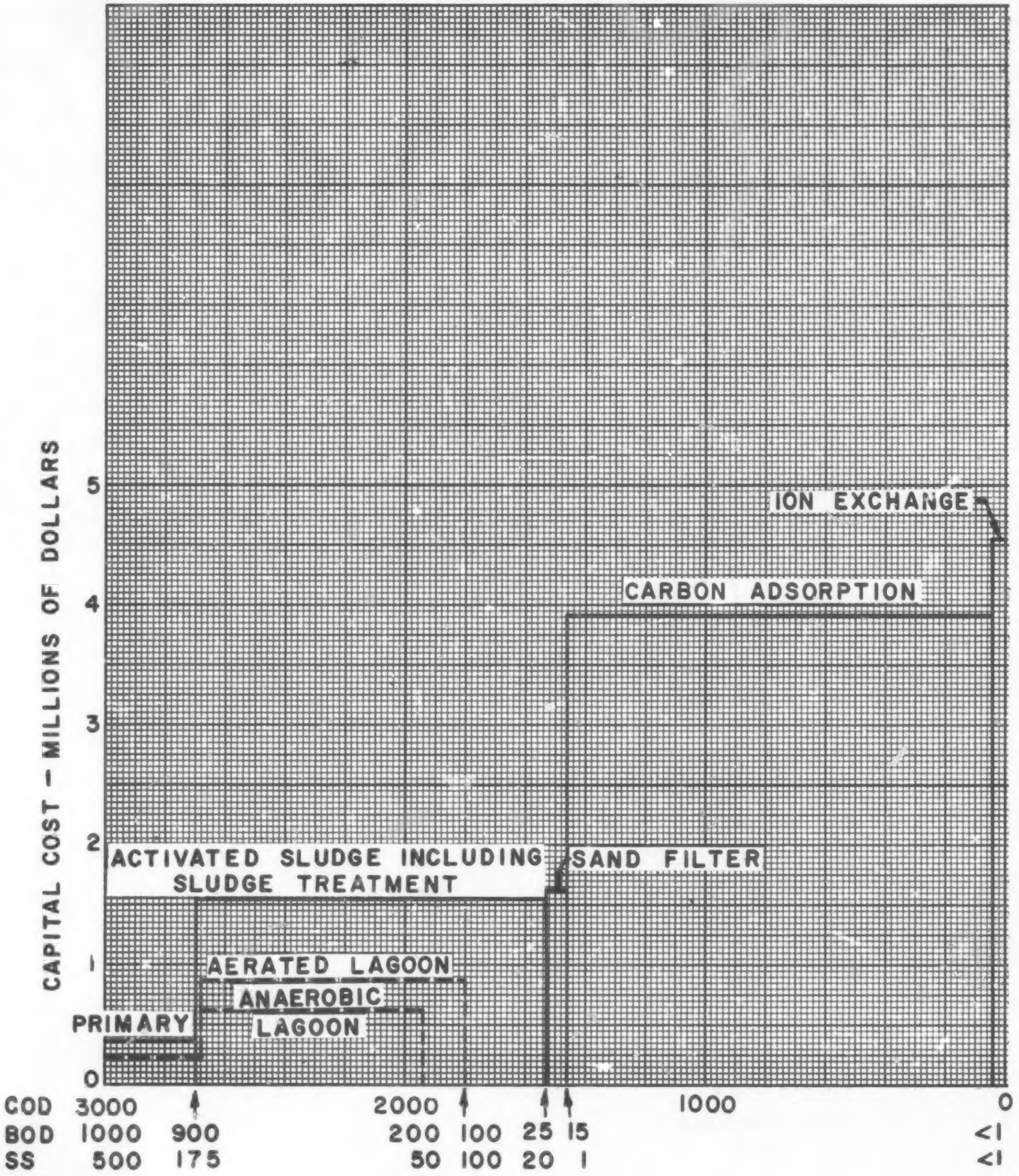


Figure 34

CAPITAL COST OF TREATMENT PLANT VS. SUBSTRATE REMOVAL

FLOW 1 MGD BOD 500 MG/L
SS 500 MG/L COD 1200 MG/L

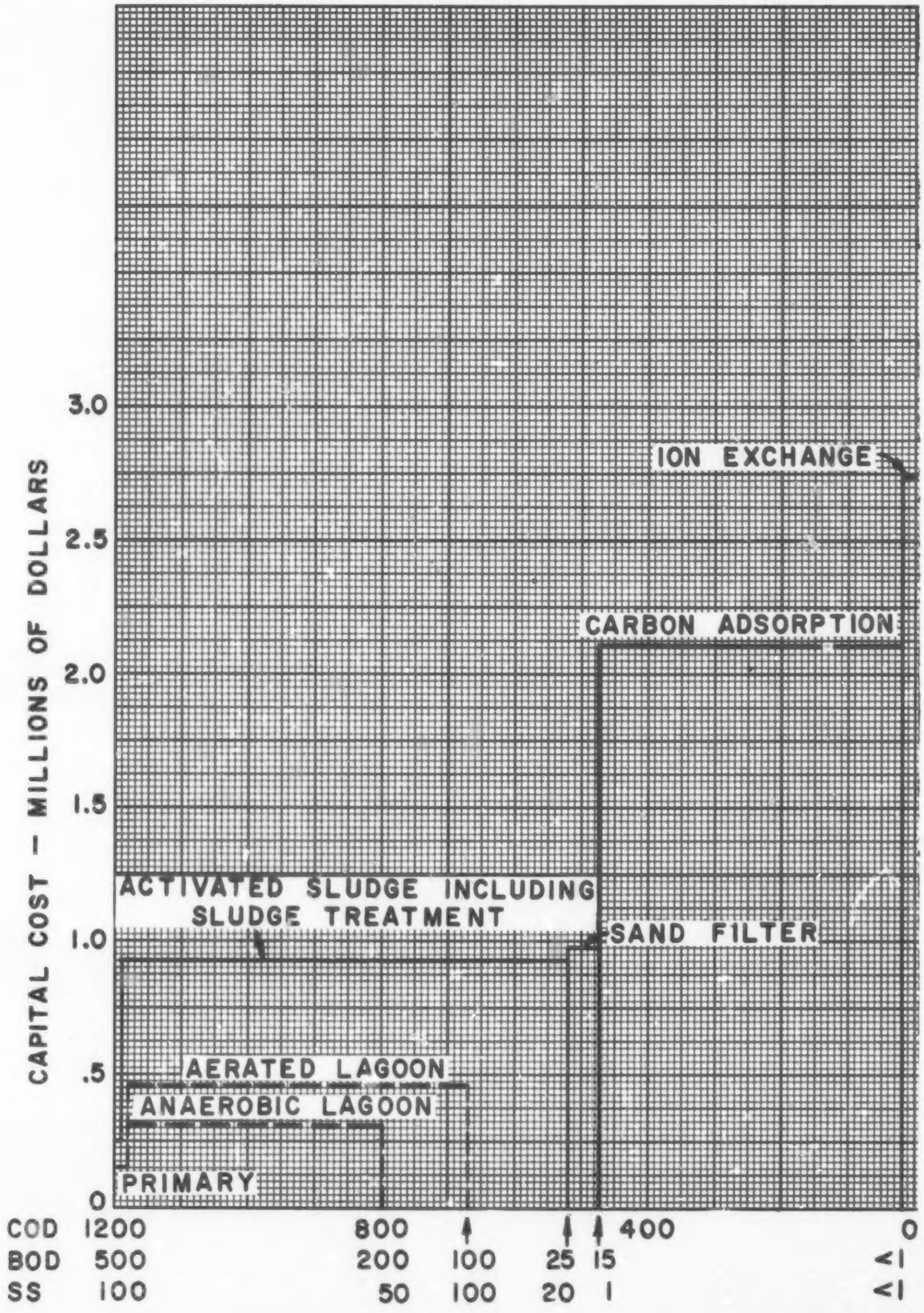


Figure 35

CAPITAL COST OF TREATMENT PLANT VS. SUBSTRATE REMOVAL

FLOW 1 MGD   BOD 500 MG/L
SS 500 MG/L   COD 1200 MG/L

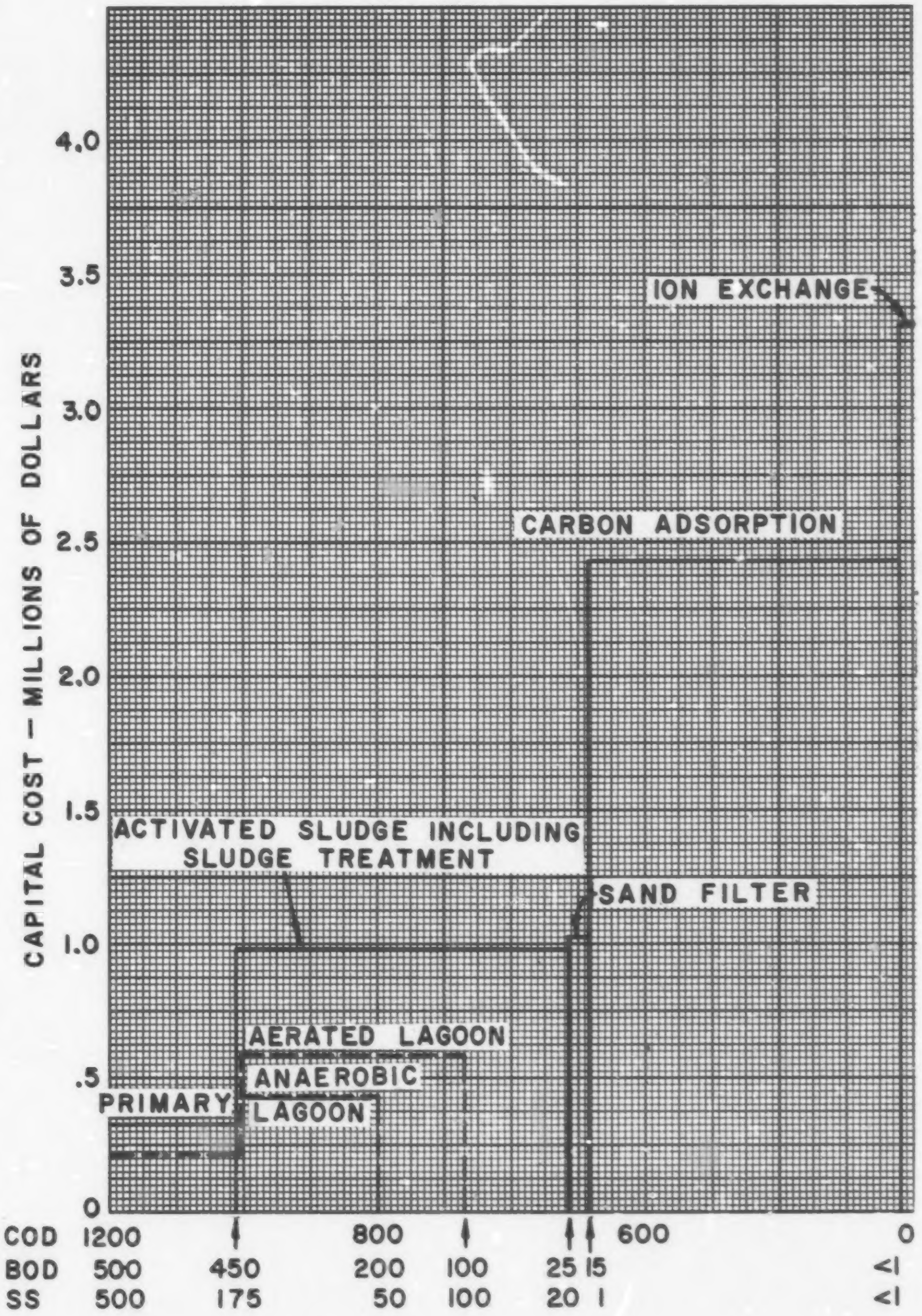


Figure 36

CAPITAL COST OF TREATMENT PLANT VS. SUBSTRATE REMOVAL

FLOW 0.5 MGD BOD 3000 MG/L
SS 100 MG/L COD 8000 MG/L

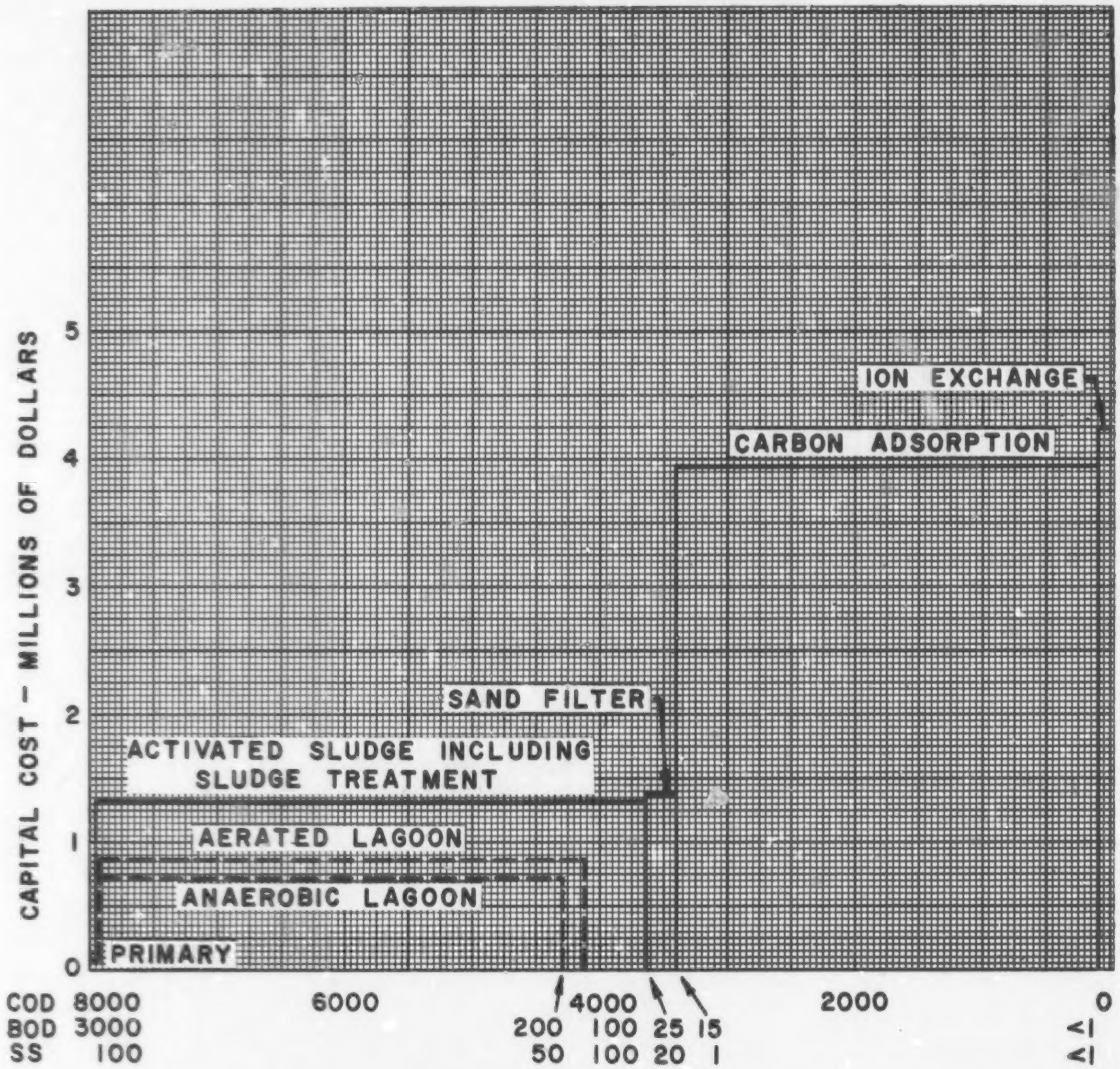
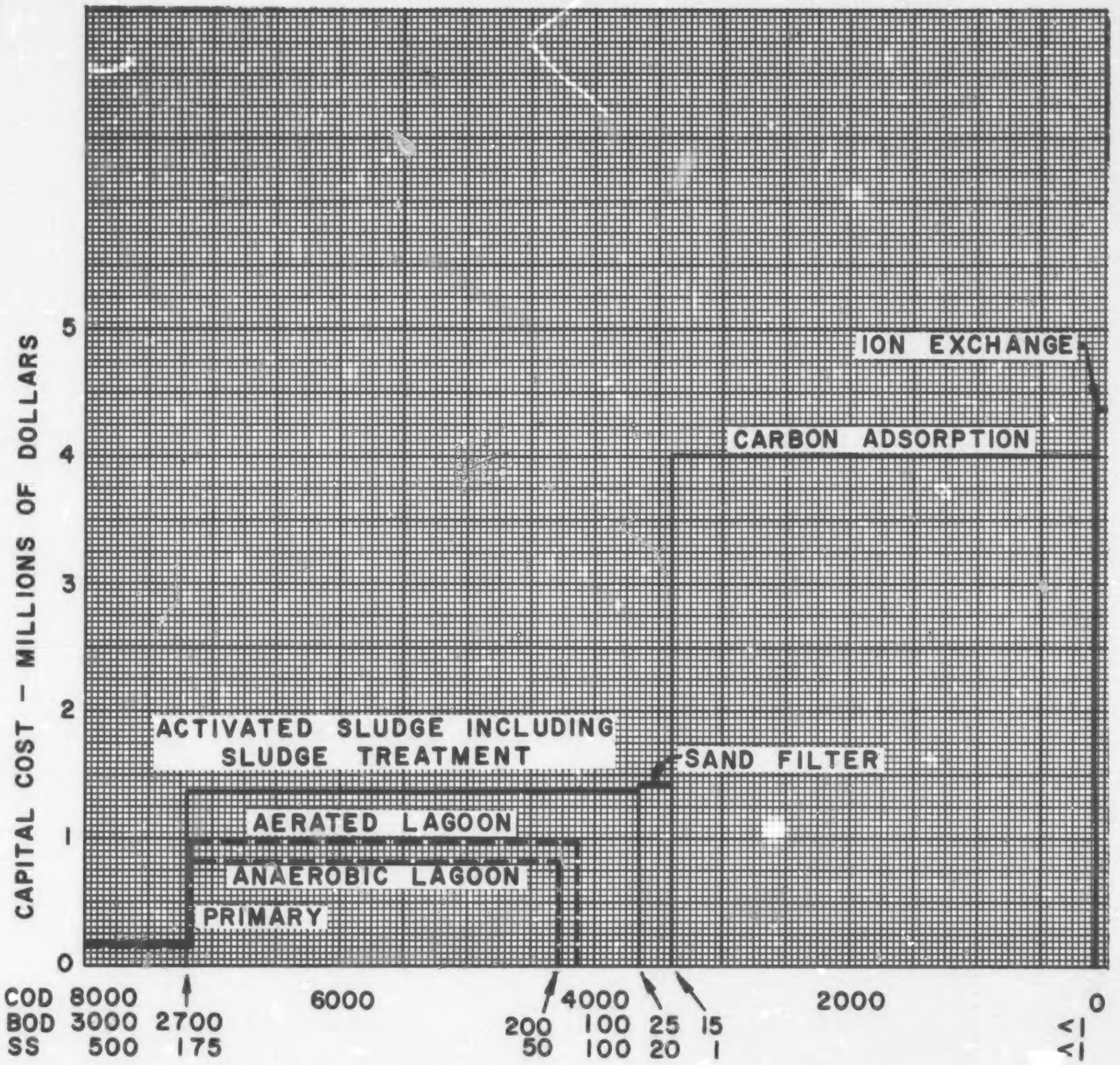
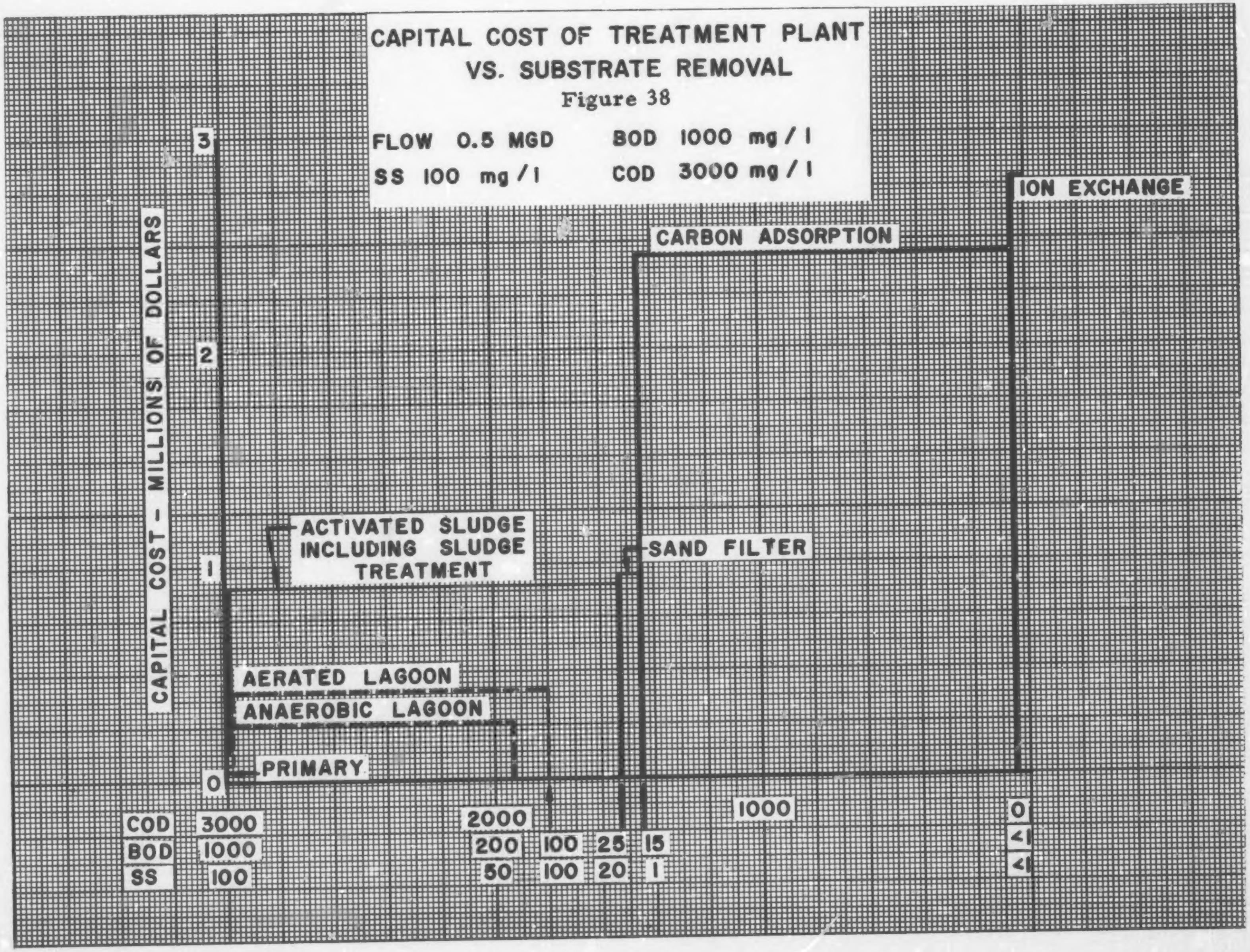


Figure 37

CAPITAL COST OF TREATMENT PLANT VS. SUBSTRATE REMOVAL

FLOW 0.5 MGD BOD 3000 MG/L
SS 500 MG/L COD 8000 MG/L





CAPITAL COST OF TREATMENT PLANT VS. SUBSTRATE REMOVAL

Figure 38

FLOW 0.5 MGD BOD 1000 mg/l

SS 100 mg/l COD 3000 mg/l

Figure 39

CAPITAL COST OF TREATMENT PLANT
VS. SUBSTRATE REMOVAL

FLOW 0.5 MGD BOD 1000 MG/L
SS 500 MG/L COD 3000 MG/L

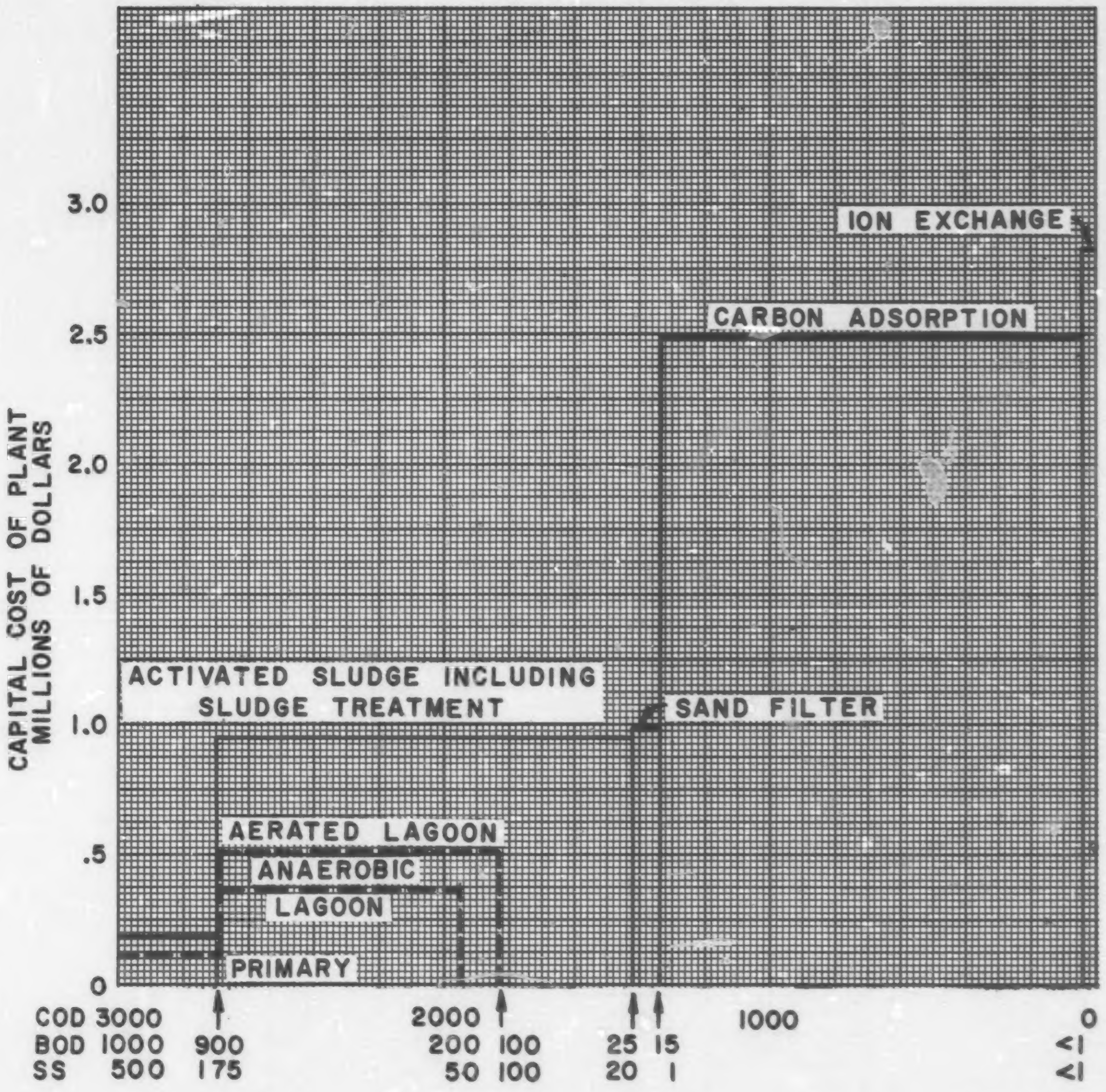


Figure 41

CAPITAL COST OF TREATMENT PLANT
VS. SUBSTRATE REMOVAL

FLOW 0.5 MGD BOD 500 MG/L
SS 500 MG/L COD 1200 MG/L

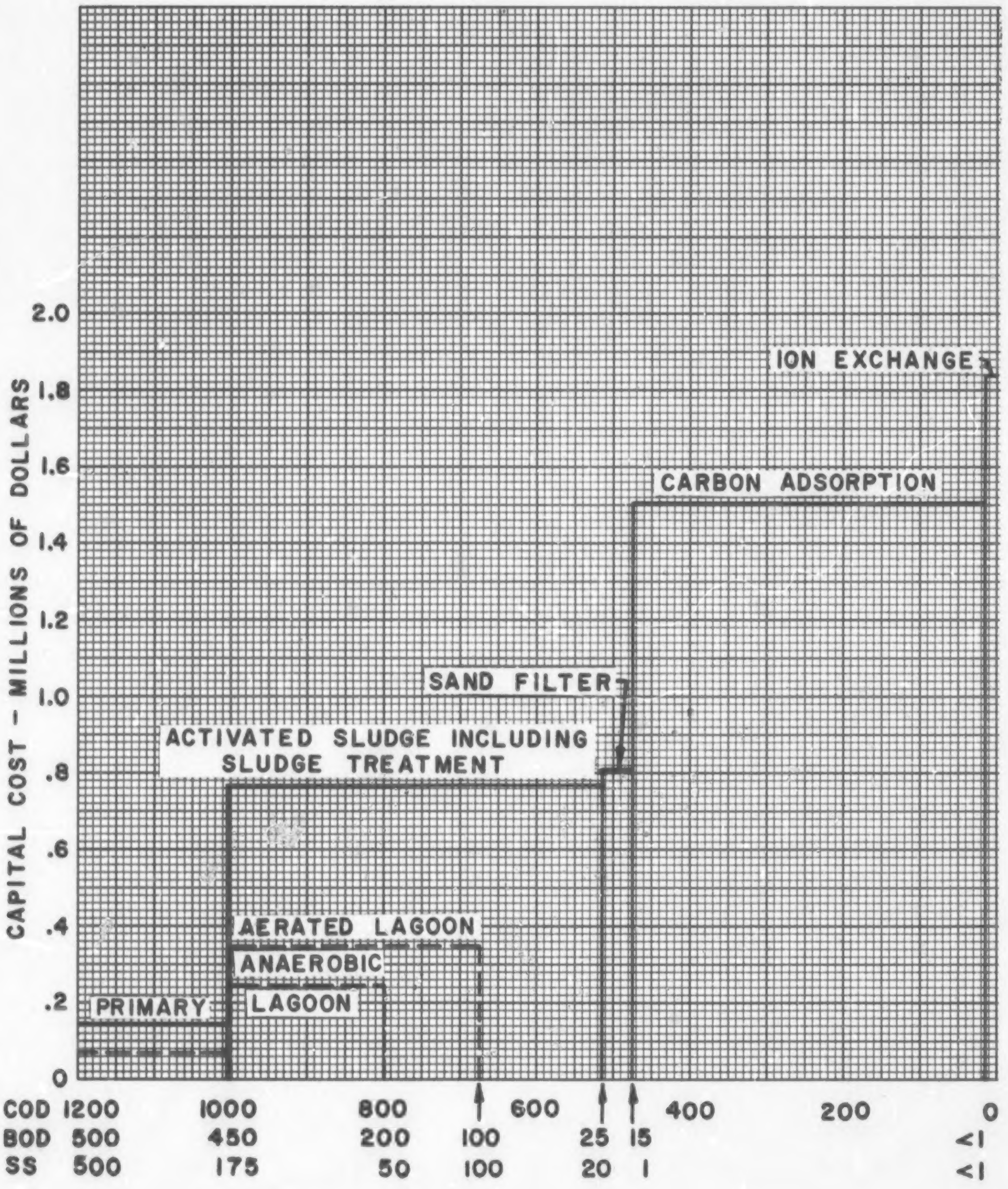
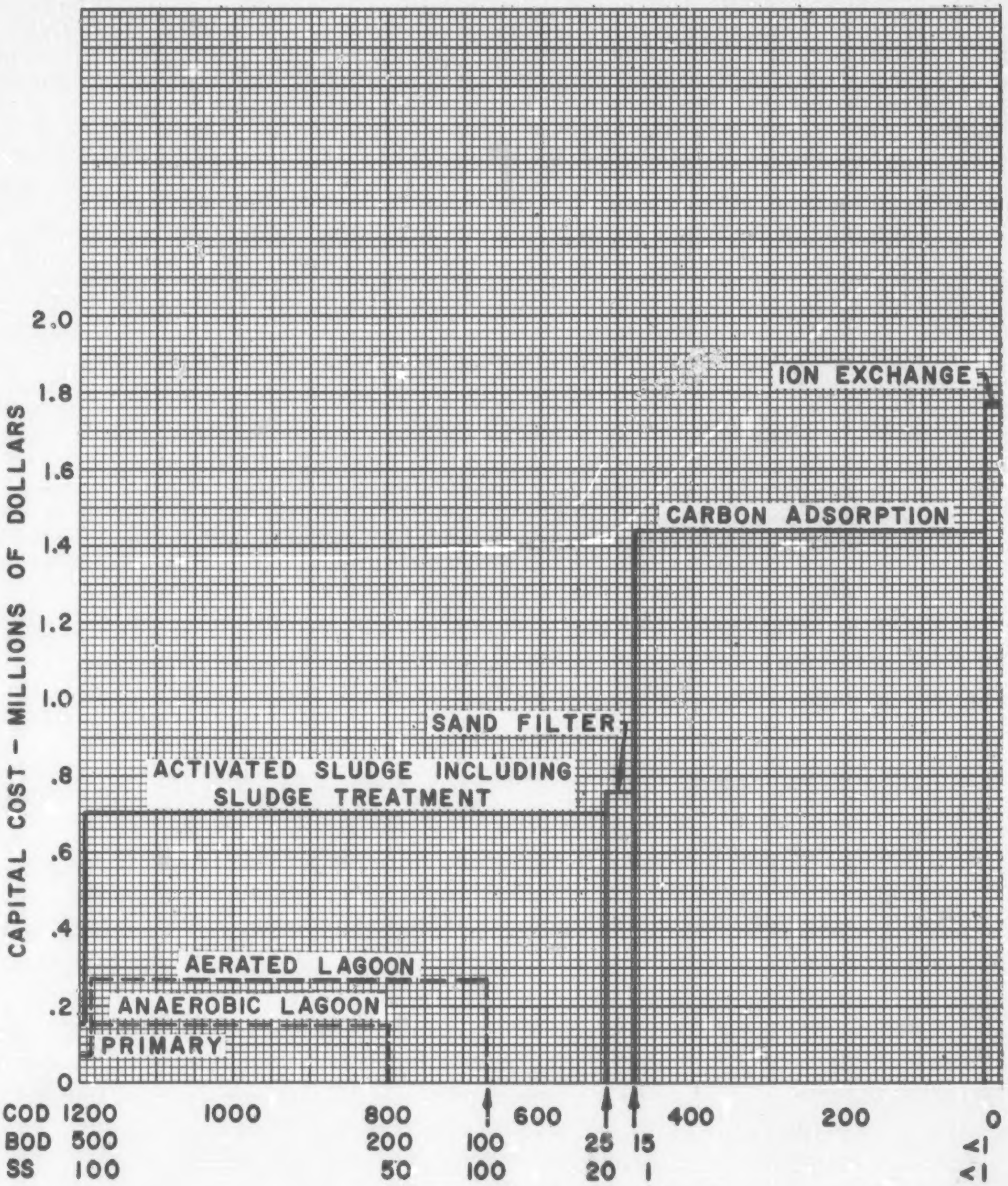


Figure 40

CAPITAL COST OF TREATMENT PLANT VS. SUBSTRATE REMOVAL

FLOW 0.5 MGD BOD 500 MG/L
SS 100 MG/L COD 1200 MG/L



XI. PROJECTED INDUSTRY COSTS

The available data indicate that in 1964 the average large plant in the organic chemicals industries had a wastewater flow of 4,564,000 gpd and that about 211 plants produced 95% of the total production of 71 billion pounds in that year. Approximately 238 plants will produce 117.2 billion pounds in 1968; 1968 data on wastewater flows are not available for the industry as a whole. The data indicate a growth rate in number of plants of about 3% per year.

Total water discharged by plants in SIC industry categories 2815 (Cyclic Intermediates) and 2818 (Organic Chemicals n.e.c. was 1509 billion gallons in 1959 and 1760 billion gallons in 1964 according to the Census of Manufactures data. Water discharged thus increased at the rate of about 3% per year during the 5-year period, while production has maintained a growth rate of about 10% per year.

On the basis of these data and the projected production figures given previously, Table XVIII presents actual and projected data for various parameters of the organic chemicals industry through 1974 on the basis of current wastewater treatment practices.

The plant survey data indicate an average wastewater flow of 7.56 gpd per ton of annual production vs. an indicated average use within the industry of 18.42 gpd per annual ton of production in 1968. The difference may be explained largely by the fact that the plants surveyed had installed waste treatment facilities that average 84.2% removal of the critical pollutant, usually referring to BOD. The proper first step in implementing waste treatment in a plant is to reduce wastewater volumes by conservation, segregation, or reuse; the data indicate that this has indeed been the practice in plants that have installed waste treatment facilities. In the absence of any other data, it may be assumed that the average wastewater production would be the average of these two figures if treatment facilities had been installed throughout the industry, i.e., 13 gpd/annual ton in 1968.

On the basis of this assumption, the industry's wastewater production if wastewater treatment facilities were to be installed would be expected to be as shown in Table XIX:

TABLE XIX

WASTEWATER PRODUCTION FOR THE INDUSTRY THROUGH 1974

Year	Wastewater, gpd/ton	Wastewater 10^9 gpy
1968	13.0	278
1969	12.2	287
1970	11.3	295
1971	10.5	304
1972	9.85	313
1973	9.23	323
1974	8.65	333

TABLE XVIII

ORGANIC CHEMICALS INDUSTRY - PROJECTIONS BASED ON CURRENT PRACTICE

	1963	1964	1965	1966	1967	1968
Number of Large Plants	-	211	217	224	231	238
Wastewater (10^9 gpy)	-	350	361	372	383	394
Production Total (10^9 lb)	71.0	78.7	88.9	100.6	111.7	122.4
Production Large Plants (10^9 lb)	-	74.8	84.5	95.5	106.1	117.2
Sales, Total (10^9 lb)	-	42.8	46.8	52.7	56.6	61.6
Sales, Total (10^9 \$)	-	8.5	9.0	9.9	10.5	11.2
Municipal Sewer Discharges (10^9 gpy)	49.8	55.1	62.2	70.4	78.2	85.7
Wastewater (gpd/annual ton)	-	25.64	23.41	21.32	19.78	18.42

	1969	1970	1971	1972	1973	1974
Number of Large Plants	245	252	260	268	276	284
Wastewater (10^9 gpy)	406	418	431	444	457	471
Production Total (10^9 lb)	135.6	150.4	166.9	183.5	201.6	221.8
Production Large Plants (10^9 lb)	128.8	142.9	158.5	174.3	191.5	210.7
Sales, Total (10^9 lb)	67.1	73.2	79.9	86.9	94.3	-
Sales, Total (10^9 \$)	11.9	12.7	13.7	14.6	15.6	-
Municipal Sewer Discharges (10^9 gpy)	94.9	105.3	116.8	128.5	141.1	155.2
Wastewater (gpd/annual ton)	17.27	16.03	14.89	13.96	13.08	12.25

The capital costs for a typical plant discharging 4.56 mgd were calculated using the unit cost method described in Sections X and XI of this report, relating costs to various levels of removal of BOD, COD, and suspended solids. The unit treatments and resulting concentrations were as shown in Table XX.

These costs are plotted in Figure 42 versus percentage removals of the various pollutants.

For the 24 plants in the survey for which sufficient information was available, the following data were obtained:

Average production = 306,670 tons per year

Average wastewater flow = 2,318,692 gpd

Average capital cost = $1,036,522

Average operating cost = $193,125

Average removal of critical pollutants = 84.2%

The following data were calculated from the above:

Average capital cost = $447/1000 gpd

Average operating cost = $83.2/1000 gpd

Average wastewater flow = 7.56 gpd/annual ton

Average capital cost = $3.38/annual ton

Average operating cost = $0.63/yr/annual ton

At 84.2% overall treatment efficiency, the average capital cost per plant was $1,036,522. The industry cost at this level would be $246,692,000 on the basis of 238 plants.

The figures in Table XIX indicate that wastewater disposed of by the industry would be 762,000 x 10^3 gpd if treatment facilities were installed throughout the industry. The capital costs in a 4.56 mgd plant would be $300 per 1000 gpd for 85% removal of BOD according to Figure 69 and the industry total thus $228,600,000.

At $447/1000 gpd the total cost would be $340,614,000. Using the calculated values for a 4.5 mgd plant, the capital cost at 83% removal of BOD would be $1,142,100 per plant or $271,819,000 for the industry in 1968 on the basis of 238 plants.

Four methods of estimating 1968 industry costs in large plants to achieve approximately 85% BOD reduction have thus yielded estimates from $228,600,000 to $340,614,000 averaging $271,931,450; these data are summarized in Table XXI.

TABLE XX

CAPITAL COSTS FOR LEVELS OF TREATMENT IN A 4.56 mgd PLANT

#	Treatment Processes Employed	BOD	COD	SS	Installed Cost	Capital Costs/1000 gpd
(0)	None	1150	3000	175	0	0
(1)	Oil Separator, Equalization, Neutralization	1150	3000	175	669,600	147
(2)	(1) + Sedimentation	1035	2700	61	804,600	176
(3)	(1) + Lagooning	200	2600	50	1,142,100	250
(4)	(2) + Activated Sludge and Final Clarifier	25	2100	20	3,194,100	700
(5)	(4) + Filtration	15	2000	1	3,423,600	751
(6)	(1) + Filtration and Deep-Well Disposal	0	0	0	7,514,100	1648

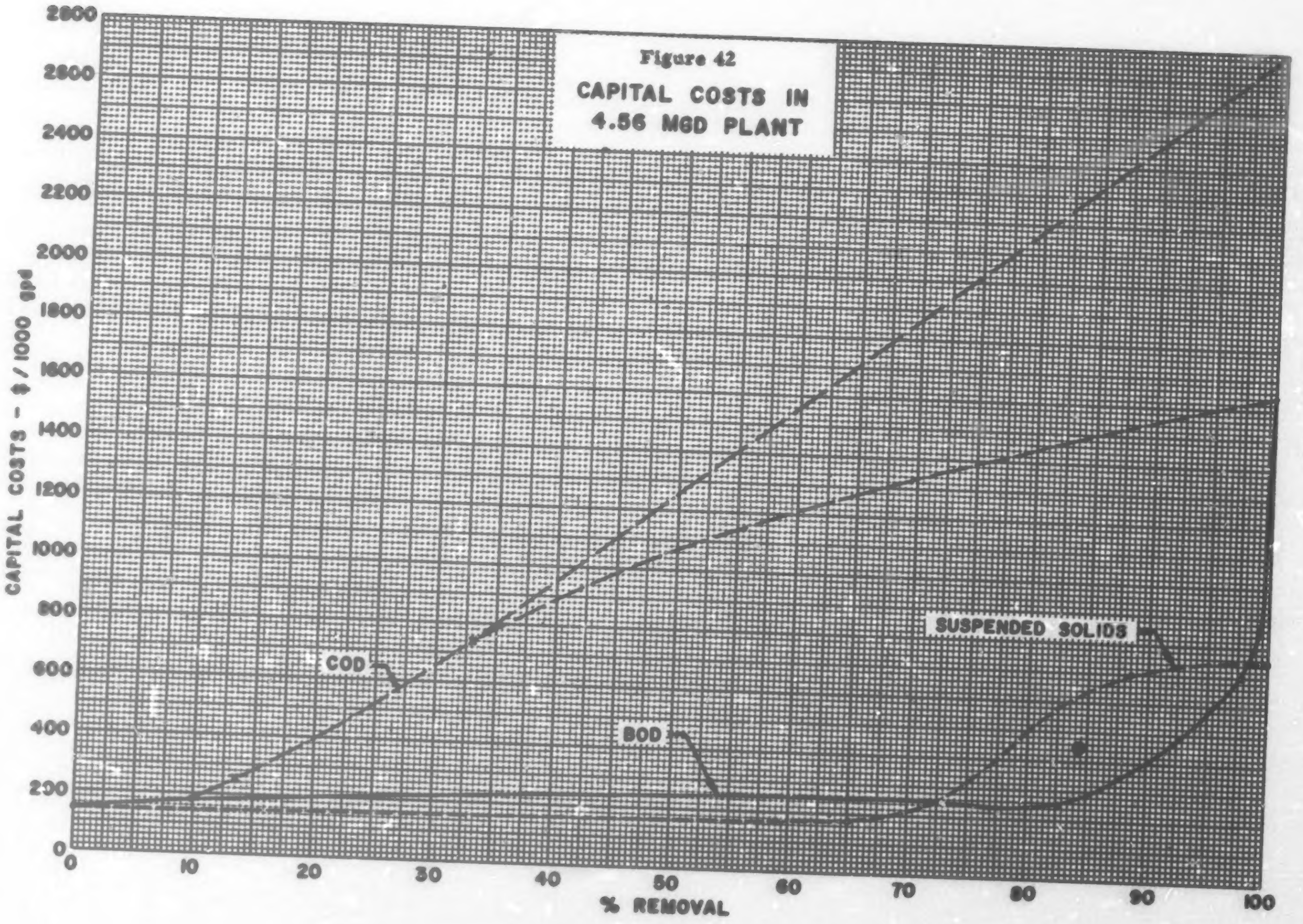


Figure 42

CAPITAL COSTS IN 4.56 MGD PLANT

TABLE XXI

ESTIMATED 1968 INDUSTRY COSTS IN LARGE PLANTS

Cost Basis	Unit	Capital Cost
Cost per plant as per sample	No. of Plants	$246,692,000
Calculated cost per plant	No. of Plants	$271,819,800
Calculated cost per 1000 gpd	Vol. of Wastewater	$228,600,000
Cost per 1000 gpd as per sample	Vol. of Wastewater	$340,614,000

The facts that the estimates based upon costs per unit of wastewater show the greatest dispersion, that those based upon costs per plant are both intermediate and that the estimate based upon calculated costs per plant and number of plants equals the average, and that the correlation analyses presented previously indicate that production-related variables rather than wastewater-related variables are of most importance, lead to the conclusion that industry estimates are most reliably made on the basis of estimated costs per plant and estimated number of plants.

In Table XXII production and wastewater figures are given for the organic chemical industry through 1974 on the basis of widespread installations of treatment facilities.

The data in Table XXII indicate that the average large plant would be expected to treat 3.2 mgd of wastewater during the period considered. The capital costs in such an average plant are given in Table XXIII versus the level of treatment attained. Such costs are projected for the industry in Table XXIV on the basis of the projected numbers of plants.

Assuming that the capital costs of discharging to a municipal sewer are those entailed in removing gross pollutants at $147/1000 gpd, the figures in Table XXV estimate the total capital costs of treatment facilities in the organic chemicals industry.

In terms of current dollars, using an average of 3.6% annual increase in the price level as has been reflected in the Engineering News Record Construction Cost Index, total industry capital costs are projected in Table XXVI.

TABLE XXII

INDUSTRY PROJECTIONS BASED UPON WIDESPREAD TREATMENT

	1968	1969	1970	1971	1972	1973	1974
Number of Large Plants	238	245	252	260	268	276	284
Production-Large Plants (10^9 #)	117.2	128.8	142.9	158.6	174.3	191.5	210.7
Production-Total (10^9 #)	122.4	135.6	150.4	166.9	183.5	201.6	221.8
Wastewater-Large Plants (10^9 gpy)	278	287	295	304	313	323	333
Wastewater-Large Plants (gpd/T/yr)	13.0	12.2	11.3	10.5	9.85	9.23	8.65
Municipal Sewer Discharges (10^9 gpy)	85.7	94.9	105.3	116.8	128.5	141.1	155.2
Municipal Sewer Discharges (10^6 gpd)	234.8	260.0	288.5	320.0	352.0	386.3	425.2

TABLE XXIII

CAPITAL COSTS VS TREATMENT LEVELS IN AVERAGE LARGE PLANT

Level	% Removal Critical Pollutants			$/1000 gpd	Cost (3.2 mgd)
	BOD	COD	SS		
1	Removal of Gross Pollutants			147	$ 470,400
2	10%	10%	65%	176	563,200
3	83%	13%	71%	250	800,000
4	98%	30%	89%	700	2,240,000
5	99%	33%	99%	751	2,403,200
6	100%	100%	100%	1648	5,273,600

TABLE XXIV

INDUSTRY CAPITAL COSTS OF IN-PLANT TREATMENT FACILITIES IN LARGE PLANTS

Treatment Level	Costs in Millions of 1968 Dollars						
	1968	1969	1970	1971	1972	1973	1974
1	112.0	115.2	118.5	122.3	126.1	129.8	133.6
2	134.0	138.0	141.9	146.4	150.9	155.4	160.0
3	190.4	196.0	201.6	208.0	214.4	220.8	227.2
4	533.1	548.8	564.5	582.4	600.3	618.2	636.2
5	572.0	588.8	605.6	624.8	644.1	663.3	682.5
6	1255.1	1292.0	1328.9	1371.1	1413.3	1455.5	1497.7

TABLE XXV

TOTAL INDUSTRY CAPITAL COSTS FOR WASTEWATER TREATMENT

	Costs in Millions of 1968 Dollars						
Treatment Level	1968	1969	1970	1971	1972	1973	1974
1	146.5	153.4	160.9	169.3	177.8	186.6	196.1
2	168.5	176.2	184.3	193.4	202.6	212.2	222.5
3	224.9	234.2	244.0	255.0	266.1	277.6	289.7
4	567.6	587.0	606.9	629.4	652.0	675.0	698.7
5	606.5	627.0	648.0	671.8	695.8	720.1	745.0
6	1289.5	1330.2	1371.3	1418.1	1465.0	1512.0	1560.2

TABLE XXVI

TOTAL INDUSTRY CAPITAL COSTS FOR WASTEWATER TREATMENT

Treatment Level	Costs in Millions of Current Dollars						
	1968	1969	1970	1971	1972	1973	1974
1	146.5	158.9	172.6	188.3	204.8	222.6	242.4
2	168.5	182.5	197.8	215.1	233.4	253.2	275.0
3	224.9	242.6	261.8	283.6	306.5	331.2	358.1
4	567.6	608.1	651.2	699.9	751.1	805.3	863.6
5	606.5	649.6	695.3	747.1	801.6	859.1	920.8
6	1289.5	1378.1	1471.4	1576.9	1687.7	1804.2	1928.4

In Figure 43, capital and operating costs are given for various levels of treatment efficiency based upon BOD and COD removals; these curves are based upon data in the technical literature. According to Equation (3) given previously, which was based upon analysis of the industry survey data, operating costs of unit waste treatment facilities are related to unit capital costs as shown by the solid line in Figure 44. The indicated points in Figure 44 are taken from the data of Figure 43 and show the extent of variation between these data.

The survey data indicate that operating costs are essentially zero for treatment facilities costing less than about $3000 per 1000 gpd, while the plotted data based upon literature data assume that zero capital costs = zero operating costs. Although a rational case can be made for the fact that operating costs in primary facilities are actually nil, the curves in Figure 45 combine estimates made from the two data sources and assume that any facility will, in fact, have an associated operating cost.

Based upon the data in Figure 45, operating costs in a 3.2 mgd treatment plant would be those shown in Table XXVII for the various levels of treatment. Operating costs for the industry would then be those shown in Table XXVIII.

TABLE XXVII

OPERATING COSTS IN AVERAGE LARGE PLANT

Level	% Removal Critical Pollutants			$/yr/1000gpd	$/yr (3.2 mgd)
	BOD	COD	S.S.		
1	Removal of Gross Pollutants			7	22,400
2	10%	10%	65%	8.5	27,200
3	83%	13%	71%	13	41,600
4	98%	30%	89%	105	336,000
5	99%	33%	99%	120	384,000
6	100%	100%	100%	350	1,120,000

TABLE XXVIII
INDUSTRY OPERATING COSTS OF FACILITIES IN LARGE PLANTS

Treatment Level	Costs in Millions of 1968 Dollars						
	1968	1969	1970	1971	1972	1973	1974
1	5.33	5.49	5.64	5.82	6.00	6.18	6.36
2	6.47	6.66	6.85	7.07	7.29	7.51	7.72
3	9.90	10.2	10.5	10.8	11.1	11.5	11.8
4	80.0	82.3	84.7	87.4	90.0	92.7	95.4
5	91.4	94.1	96.8	99.8	102.9	106.0	109.1
6	266.6	274.4	282.2	291.2	300.2	309.1	318.1

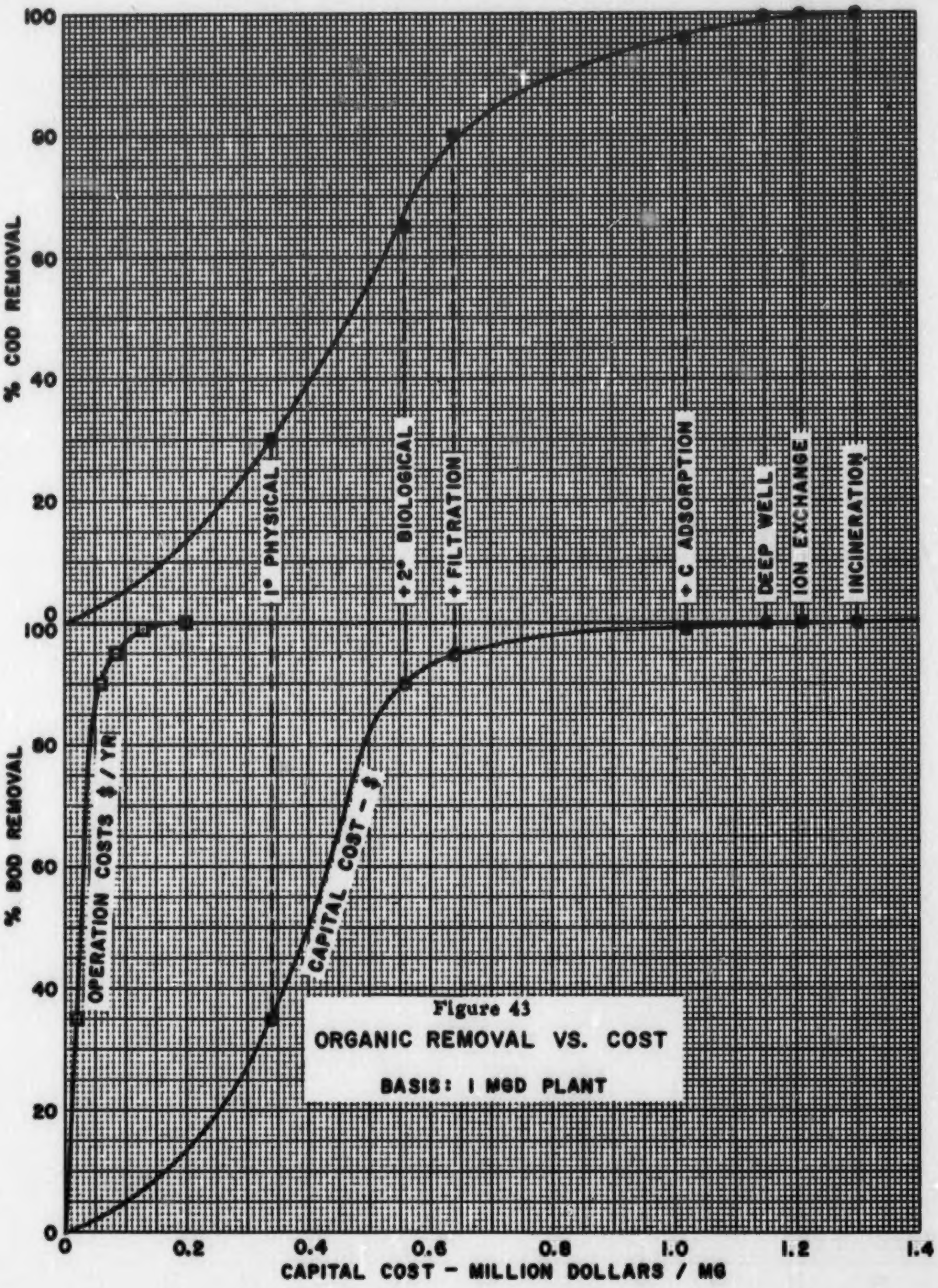


Figure 43
ORGANIC REMOVAL VS. COST
BASIS: 1 MGD PLANT

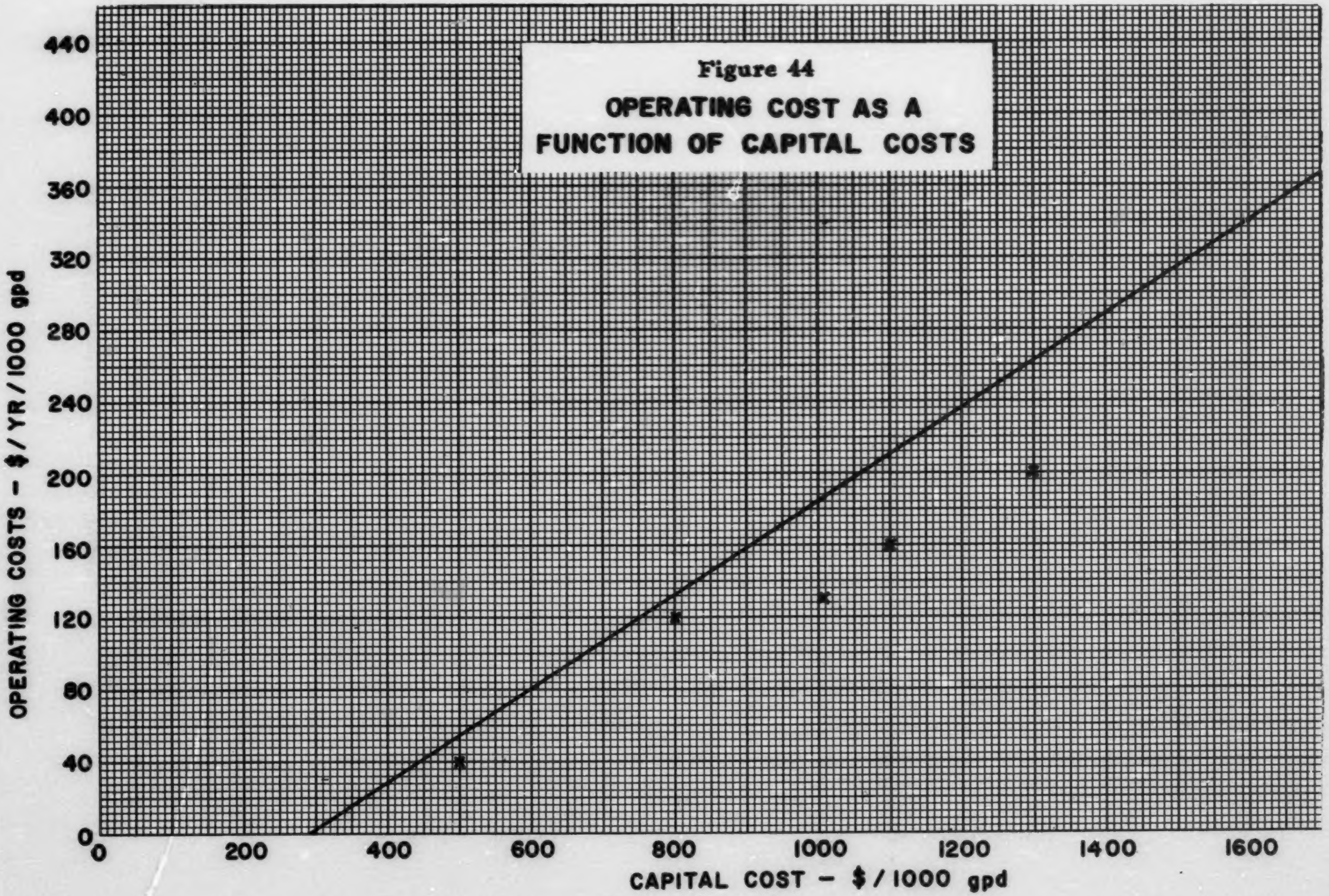


Figure 44

OPERATING COST AS A FUNCTION OF CAPITAL COSTS

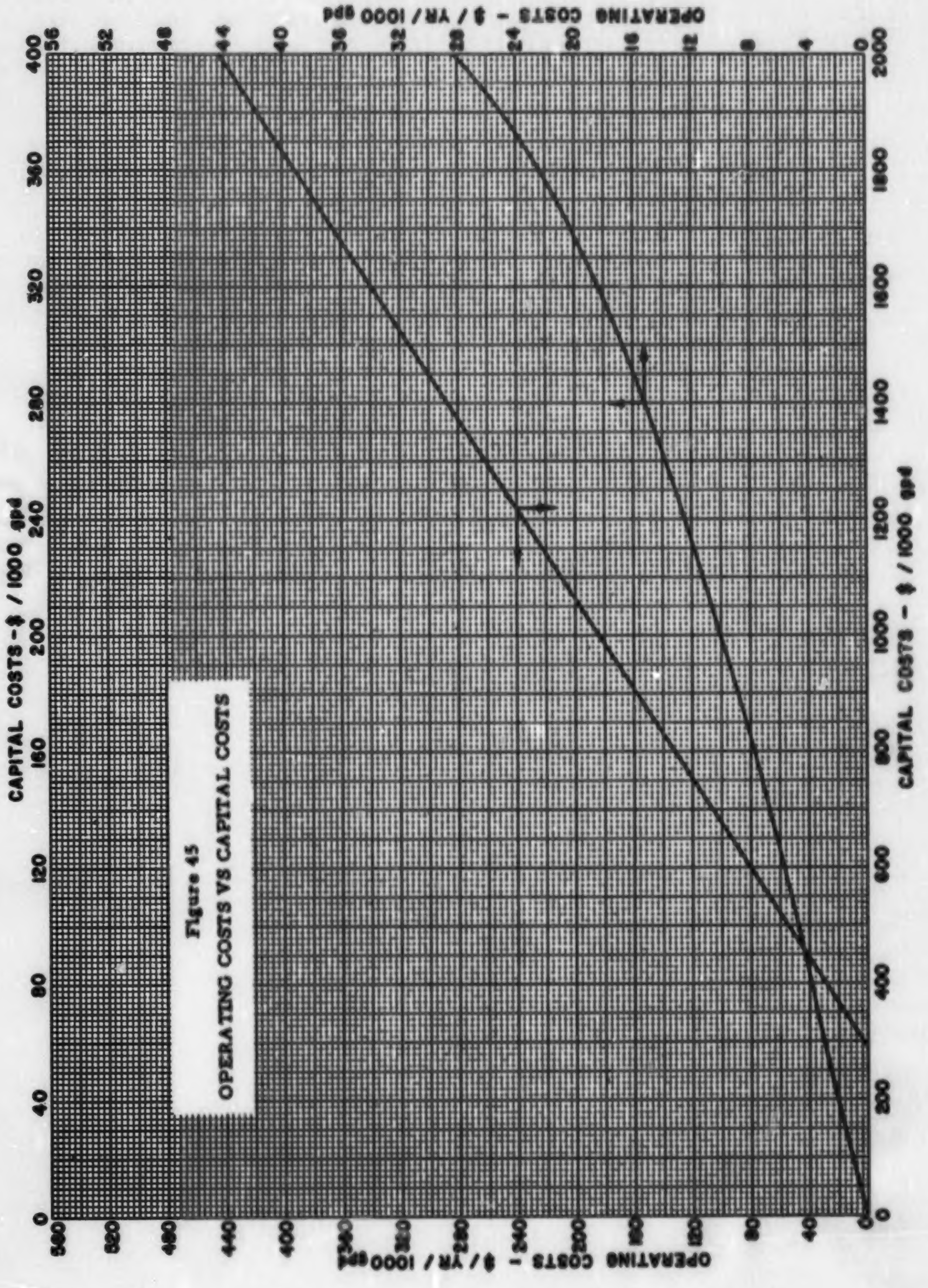


Figure 45
OPERATING COSTS VS CAPITAL COSTS

Assuming that the operating costs associated with the discharge of industrial wastes to municipal sewers are 10 cents per 1000 gpd, the total operating costs for the industry in 1968 dollars are given in Table XXIX in 1968 dollars and in Table XXX in current dollars.

TABLE XXIX

TOTAL INDUSTRY OPERATING COSTS FOR WASTEWATER TREATMENT

Treatment Level	Costs in Millions of 1968 Dollars						
	1968	1969	1970	1971	1972	1973	1974
1	13.9	15.0	16.1	17.5	18.9	20.3	21.9
2	15.0	16.2	17.4	18.8	20.2	21.6	23.2
3	18.5	19.7	21.0	22.5	24.0	25.6	27.3
4	88.6	91.8	95.2	99.1	102.9	106.8	110.9
5	100.0	103.6	107.3	111.5	115.8	120.1	124.6
6	275.2	283.9	292.7	302.9	313.1	323.2	333.6

TABLE XXX

TOTAL INDUSTRY OPERATING COSTS FOR WASTEWATER TREATMENT

Treatment Level	Costs in Millions of Current Dollars						
	1968	1969	1970	1971	1972	1973	1974
1	13.9	15.5	17.3	19.5	21.9	24.4	27.3
2	15.0	16.8	18.7	20.9	23.4	25.9	28.9
3	15.5	20.4	22.5	25.0	27.8	30.7	34.0
4	88.6	95.1	102.1	110.2	119.4	128.3	138.1
5	100.0	107.3	115.1	124.0	134.3	144.2	155.1
6	275.2	294.1	314.1	356.8	363.2	388.2	415.3

XII. METHODOLOGY FOR WASTEWATER TREATMENT COSTS DETERMINATION

The methods which have been developed and used in this study of the organic chemicals industry can be utilized to determine wastewater treatment costs for other industries. The methodology is intended to be used in establishing and projecting costs for an industry or for groups of industries, rather than for individual plants. Costs estimates for individual plants are readily calculable by conventional engineering techniques to almost any degree of precision desired, depending upon the effort to be expended and the intended uses of the information. Costs for an industry could, of course, be determined precisely by calculating the costs of treatment facilities for each individual plant in an industry and totalling these costs. Alternatives to this obviously impractical method are to estimate the number of plants involved and multiply by the "average" cost per plant or to estimate the volume of wastewater involved and multiply by the "average" cost per unit volume of wastewater; such alternative methods are practical and after a degree of accuracy sufficient for purposes of industry-wide planning and economic impact studies. The suggested methods for determining the total costs to an industry of attaining specified degrees of wastewater effluent quality over a time period are outlined below as a series of steps.

STEP 1: Characterization of the Industry

The industry to be studied must be defined and its general characteristics understood as a first step. Although the SIC definitions are not completely satisfactory, most data are given in terms of these categories; as a practical matter; therefore, the industry to be studied must be defined in terms of one or more 4-digit SIC groups. The general nature of the industry's production processes and operating philosophy should be understood, since the former, of course, generate the wastewaters and the latter influence to a large degree the methods by which pollution control is implemented; such factors as rate of technological change, average process and/or equipment lives, degree and types of competition, etc. in the industry should be understood. Information on production processes are generally found in the technical literature of the industry, in engineering texts, in trade association publications and in some of the books on industrial waste treatment. Information on other aspects of the industry is to be found in Department of Commerce publications, trade association publications, and business literature.

STEP 2: Projection of Industry Growth

The growth of the industry should be projected over the time period set for purposes of the study. Projections should be made in terms of physical production units for the industry as defined. Additional data such as growth in terms of values of products, by industry segment, by geographical region, for closely related or competitive industries, etc. may prove to be of value for analytical purposes, but the primary data of interest is that in terms of physical production units. Such information can be obtained from Dept. of Commerce publications, trade association publications, technical societies, trade magazines, and business literature.

STEP 3: Characterization of Wastewaters

Wastewaters of the industry should be characterized in terms of typical volumes per unit of product and in terms of typical concentrations at the most significant pollutants. The significant pollutants will vary from one industry to another; many industries produce wastewaters containing dozens or even hundreds of different pollutants, but two or three specific materials or classes of materials are usually of controlling significance. General parameters of wastewater contamination such as biochemical oxygen demand, chemical oxygen demand, suspended solids, oil and color are generally more useful than are concentrations of specific compounds. The reason, of course, lies in the fact that the general parameters relate to both effluent quality and to the likely methods of waste treatment. Such information is most likely to be found in the industrial wastewater technical literature, i.e., texts, study reports, periodicals, and proceedings of technical meetings.

STEP 4: Wastewater Treatment Methods

The methods of wastewater treatment applicable to the wastewaters of the particular industry should be determined and generally classified in relation to the degree of treatment or quality of effluent obtainable with the individual processes. The methods to be considered will vary considerably from one industry to another and will be primarily determined by the volumes of wastewaters to be handled, the nature of the pollutants, and the general experience within the industry with various treatment methods. For purposes of such a study, new or unique methods for which little operating or cost experience is available should not be considered. Two factors of importance here are the degree to which wastewaters are likely to be treated for reuse and the extent to which the industry discharges to municipal sewers. Such information is likely to be found again in the industrial wastewater technical literature.

STEP 5: Plant Survey Data Acquisition

Data on specific plants in the industry operating wastewater treatment facilities should be obtained in order to verify the applicability of generalized data to the specific industry studied and to determine the parameters of the industry operations which best define wastewater treatment costs. The Industrial Waste Treatment Practices Data Form provides a convenient format for obtaining data from specific plants and its use is recommended for this purpose. This form will insure that the needed data are obtained and that the data will be in a readily usable form. The number of plants surveyed will depend upon the nature and size of the industry and, of course, the extent to which data can be obtained. As much of the data indicated on the Form should be obtained as possible for each plant; some data will be useful even when all that would be desired cannot be obtained from each plant. Complete data on production, wastewater volumes, effluent quality or treatment efficiency, capital costs of facilities, and operating costs of facilities on at least 15 to 20 plants should be obtained as a minimum if statistical analyses of the data are to be of use. Such data are best obtained through plant interviews, but much of such data can be obtained from the industrial wastewater technical literature.

STEP 6: Survey Data Analysis

The plant survey data should be analyzed to determine the extent to which it is representative of the industry as a whole and to determine the nature of the relationships between costs and such factors as production, wastewater volumes, and treatment efficiencies. The variables X_1 through X_6 defined in Section IX provide a basis for analyzing these relationships, using multiple correlation techniques. Comparisons of geographical distributions, plant sizes, product mixes, etc. between the sample data and those for the industry as a whole provide basis for determining the adequacy of the sample; data for the industry for such comparisons must generally be obtained from trade sources, since the Department of Commerce data are not sufficiently detailed for most industries.

STEP 7: Costs of Unit Wastewater Treatment Methods

The costs of unit wastewater treatment methods applicable to the industry should be obtained in terms of daily wastewater volumes in plants of sizes typical of the industry, or in terms which can be translated into such units. The unit costs given in Section X of this report cover many of the generally applicable treatment methods. For some industries such as metal finishing or steel mills the unit costs of treating such wastewaters as plating solutions, spent pickle liquors, etc. can be obtained from the industrial wastewater literature.

STEP 8: Costs Related to Effluent Quality

The unit cost data must be related to effluent quality in a manner similar to that outlined in Section XI of this report for plants of typical size and effluent characteristics. The pollutants of importance and the extent to which degree of removal can be defined and related to costs will vary with the industry selected for study and little of a specific nature can be said here beyond the fact that the figures of Section XI illustrate the goal of such an effort.

STEP 9: Wastewater Projections for the Industry

The wastewater generation by the industry should be estimated for the period of interest, using all available data. It is here that opinions and assumptions expect a very strong influence; wastewater generation will be a function not only of production, but of the very methods installed to reduce pollution as well as the nature of the industry's projected growth. All of the statistical data should be used in such projections, but due regard should be taken of available expert opinion within the industry of the nature of projected water utilization practices.

STEP 10: Industry Cost Projections

Projection of the industry costs become a mechanical matter at this stage; all of the necessary data have been accumulated. Depending upon the relative reliabilities of the various data and the indicated nature of the cost determining industry parameters, the projections for the industry are made using the most likely data set. In the present study production-related parameters were shown to be of prime importance, a reliable estimate of numbers of plants was available, and the "average" plant costs were closely estimated by two alternative techniques. In another industry the most likely set of data might well be different; the only general guidance that can be provided is to show the considerations involved as outlined in Section XII of this report.

APPENDIX A

INDUSTRIAL WASTE TREATMENT PRACTICES DATA FORM

DOCUMENT TO DATA CENTER ______________ by ______________ sh. _____ of _____
DATE NAME
REVISION TO DATA CENTER ______________ by ______________ Rev. ☐☐
DATE NAME

INDUSTRIAL WASTE TREATMENT PRACTICES DATA FORM

CARD 1 GENERAL INFORMATION

PLANT NO. ☐☐☐☐☐ 1 2 3 4 5 INITIAL FORM NO. ☐☐☐☐☐☐ 6 7 8 9 10 11 INITIAL ? ☐ YES ☐ NO

INDUSTRY ______________ S.I.C. NO. ☐☐☐☐ 12 13 14 15

FIRM ______________ PLANT ______________

YEAR PLANT CONSTRUCTED ☐☐☐☐ 16 17 18 19 STATE ______________ CODE ☐☐ 20 21

CITY AND/OR COUNTY ______________ CODE ☐☐☐☐ 22 23 24 25

STATISTICAL AREA ______________ CODE ☐☐☐ 26 27 28

ECONOMIC AREA ______________ CODE ☐☐☐ 29 30 31

WATER RESOURCE REGION ______________ CODE ☐☐ 32 33

RECEIVING STREAM ______________ CODE MAJOR ☐☐ 34 35 MINOR ☐☐ 36 37

DATE OF DATA ACQUISITION MO. ☐☐ 38 39 YR. ☐☐ 40 41 BASE YEAR ☐☐☐☐ 42 43 44 45

SINGLE PLANT FIRM ☐ 46 MULTIPLANT FIRM ☐ 47

SIZE OF FIRM: GROSS SALES ($ 1000 PER YEAR) ☐☐☐☐☐☐☐ 48 49 50 51 52 53 54

SUBSIDIARY OF ______________ ☐ 55

SIZE OF FIRM IN THE INDUSTRY (PERCENT OF THE MARKET) ☐☐☐ 56 57 58

SIZE OF FIRM IN THE INDUSTRY: LARGE ☐ 59 MEDIUM ☐ 60 SMALL ☐ 61

OWNERSHIP OF FIRM: PUBLICILY TRADED STOCK ☐ 62 CLOSELY HELD ☐ 63

PUBLICLY REGULATED FIRM ☐ 64 DEFENSE - ORIENTED ☐ 65

REVISION DATE ______________ REV. ☐☐ 78 79 END OF CARD 1 80

INDUSTRIAL WASTE TREATMENT PRACTICES DATA FORM

CARD 2 BASES FOR TREATMENT DECISIONS

SAME AS CARD.1 (1–11) Data Form No. ☐☐☐☐☐☐ (12 13 14 15 16 17)

Data By ________________ (NAME) CODE PERSON ☐☐ (18 19) SOURCE ☐☐ (20 21) DATE MO. ☐☐ (22 23) YR. ☐☐ (24 25)

Basis Of Treatment Standards:

Common Law ☐ 26 Statute Law ☐ 27 Public Opinion ☐ 28 Within Firm ☐ 29

Courts: Federal ☐ 30 State ☐ 31 Local ☐ 32 Order ☐ 33 Precedent ☐ 34

Agencies: Federal ☐ 35 State ☐ 36 Inter State ☐ 37 Local ☐ 38

Regulations ☐ 39 Order ☐ 40 Conference ☐ 41 Hearsay ☐ 42

Action Initiation Within The Firm:

Corporate ________________ CODE ☐☐☐ (43 44 45)

Plant ________________ CODE ☐☐☐ (46 47 48)

Basis Of Action Decisions

Public Opinion ☐ 49 Law ☐ 50 Legal Action ☐ 51 Economic Incentive ☐ 52

Other ________________ CODE ☐☐☐ (53 54 55)

Basis Of Treatment Decision

Least Cost: Total ☐ 56 Operating ☐ 57 Capital ☐ 58 Economic Return ☐ 59

Water Conservation ☐ 60 Minimum Compliance ☐ 61 Ultimate Treatment ☐ 62

Other ________________ CODE ☐☐☐ (63 64 65)

Responsibility For Action Decision:

Corporate ________________ CODE ☐☐☐ (66 67 68)

Plant ________________ CODE ☐☐☐ (69 70 71)

Responsibility For Treatment Decision:

Corporate ________________ CODE ☐☐☐ (72 73 74)

Plant ________________ CODE ☐☐☐ (75 76 77)

SAME AS CARD 1 (78–79) END OF CARD 2 (80)

INDUSTRIAL WASTE TREATMENT PRACTICES DATA FORM

CARDS 3 PLANT PRODUCTION INFORMATION I

SAME AS CARD 2
1 17

Product		Production Capacity		
______________	CODE ☐☐☐☐ 18 19 20 21	______________	AMOUNT ☐☐☐ 22 23 24	UNIT ☐ 25
______________	CODE ☐☐☐☐ 26 27 28 29	______________	AMOUNT ☐☐☐ 30 31 32	UNIT ☐ 33
______________	CODE ☐☐☐☐ 34 35 36 37	______________	AMOUNT ☐☐☐ 38 39 40	UNIT ☐ 41
______________	CODE ☐☐☐☐ 42 43 44 45	______________	AMOUNT ☐☐☐ 46 47 48	UNIT ☐ 49
______________	CODE ☐☐☐☐ 50 51 52 53	______________	AMOUNT ☐☐☐ 54 55 56	UNIT ☐ 57
______________	CODE ☐☐☐☐ 58 59 60 61	______________	AMOUNT ☐☐☐ 62 63 64	UNIT ☐ 65
______________	CODE ☐☐☐☐ 66 67 68 69	______________	AMOUNT ☐☐☐ 70 71 72	UNIT ☐ 73

Production Schedule ______________________________ **Hrs. Per. Mo.** ☐☐☐ 74 75 76

Remarks :

____

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____

____

____

NO. OF CARDS 3 ☐ 77 SAME AS CARD 2 78 79 **END OF CARD** 3 80

INDUSTRIAL WASTE TREATMENT PRACTICES DATA FORM

CARDS 4 PLANT PRODUCTION INFORMATION II

SAME AS CARD 3 (1–17)

PRINCIPAL WASTE-PRODUCING PRODUCTION PROCESSES:

____________	CODE ☐☐☐☐ 18 19 20 21	____________	CODE ☐☐☐☐ 22 23 24 25
____________	CODE ☐☐☐☐ 26 27 28 29	____________	CODE ☐☐☐☐ 30 31 32 33
____________	CODE ☐☐☐☐ 34 35 36 37	____________	CODE ☐☐☐☐ 38 39 40 41

SIZE OF PLANT:

Employment (10^2) ☐☐☐ 42 43 44 Value Added ($\$10^4$/YR.) ☐☐☐☐ 45 46 47 48

Plant Area (Acres) ☐☐☐☐ 49 50 51 52 Production ____________ AMOUNT ☐☐☐ 53 54 55 UNIT ☐ 56

Size In Industry: Small ☐ 57 Medium ☐ 58 Large ☐ 59

AGE OF PLANT:

Age In Years ☐☐ 60 61 Years Since Major Modification ☐☐ 62 63

LEVEL OF TECHNOLOGY:

Old ☐ 64 Average ☐ 65 Advanced ☐ 66 Typical ☐ 67 Unique ☐ 68

RAW MATERIALS USED:

____________________________ CODE ☐☐ 69 70

____________________________ CODE ☐☐ 71 72

____________________________ CODE ☐☐ 73 74

____________________________ CODE ☐☐ 75 76

NO. OF CARDS 4 ☐ 77 SAME AS CARD 3 (78–79) END OF CARD 4 80

INDUSTRIAL WASTE TREATMENT PRACTICES DATA FORM

CARD 5 WATER USES

SAME AS CARD 4 (1–17)

WATER USE IN PLANT:

		Cost (¢/1000 gal. used)			
Primary Purpose	Major Source	Total	Treatment	Principal Treatment	Use (10⁴ gal.)
Total Cooling	CODE ☐☐☐ 18 19 20	☐☐☐ 21 22 23	☐☐☐ 24 25 26	CODE ☐☐☐ 27 28 29	☐☐☐ 30 31 32
Total Process	CODE ☐☐☐ 33 34 35	☐☐☐ 36 37 38	☐☐☐ 39 40 41	CODE ☐☐☐ 42 43 44	☐☐☐ 45 46 47
Total Other	CODE ☐☐☐ 48 49 50	☐☐☐ 51 52 53	☐☐☐ 54 55 56	CODE ☐☐☐ 57 58 59	☐☐☐ 60 61 62

Total Water Intake ____________________ (10^4 gal.) ☐☐☐☐ 63 64 65 66

Total Water Use ____________________ (10^4 gal.) ☐☐☐☐ 67 68 69 70

PROCESS WATER QUALITY:

Completely Satisfactory ☐ 71 Marginal ☐ 72 Unsatisfactory ☐ 73

____

____

____

PROCESS WATER QUALITY REQUIREMENTS:

____

____

____

____

____________________ CODES ☐ 74 ☐ 75 ☐ 76 ☐ 77

SAME AS CARD 4 (78–79) END OF CARD 5 (80)

INDUSTRIAL WASTE TREATMENT PRACTICES DATA FORM

CARD 6 CHARACTERISTICS OF WASTE STREAMS.

SAME AS CARD 5 (1–17)

Waste Stream No. ☐☐ (18 19) Of ☐☐ (20 21) Waste Streams In Plant

Total Plant Effluent Calculated As Weighted Average		☐	22
Flow ________	gpd	☐☐☐☐ 10X ☐	23 24 25 26 / 27
1. Oil ________	mg/l	☐☐☐☐	28 29 30 31
2. Biochemical Oxygen Demand ________	mg/l	☐☐☐☐	32 33 34 35
3. Chemical Oxygen Demand ________	mg/l	☐☐☐☐	36 37 38 39
4. Total Organic Carbon ________	mg/l	☐☐☐☐	40 41 42 43
5. Suspended Solids ________	mg/l	☐☐☐☐	44 45 46 47
6. Temperature ________	°F	☐☐☐	48 49 50
7. Alkalinity ________	mg/l	☐☐☐☐	51 52 53 54
8. Acidity ________	mg/l	☐☐☐☐	55 56 57 58
9. Total Dissolved Solids ________	mg/l	☐☐☐☐	59 60 61 62
10. Nitrogen ________	mg/l	☐☐☐☐	63 64 65 66
11. Phosphorous ________	mg/l	☐☐☐☐	67 68 69 70
12. Others ________	mg/l	☐☐☐ + ☐ 10X ☐ CODE ☐	71 72 73 / 74 / 75 / 76

Remarks: ________

____

____

NO. OF CARDS 6 ☐ (77) **SAME AS CARD 5** (78–79) END OF CARD 6 (80)

INDUSTRIAL WASTE TREATMENT PRACTICES DATA FORM

CARDS 7 WASTE TREATMENT AND/OR REDUCTION PRACTICES

SAME AS CARD 6 (1–17)

Practice No. ☐☐ (18 19) Of ☐☐ (20 21) Practices In Use In Plant

Practice Instituted In Connection With Abatement Of Pollution From Waste Stream Nos: ☐☐ (22 23) ☐☐ (24 25) ☐☐ (26 27) ☐☐ (28 29)

Data On This Card Is For A Complete Treatment Plant. ________ ☐ (30)

1. Unit Treatment ________ ☐☐☐ (31 32 33)
2. Unit Treatment ________ ☐☐☐ (34 35 36)
3. Unit Treatment ________ ☐☐☐ (37 38 39)
4. Unit Treatment ________ ☐☐☐ (40 41 42)
5. Unit Treatment ________ ☐☐☐ (43 44 45)

Installation Dates : Initial, 19 ☐☐ (46 47) Last Modified, 19 ☐☐ (48 49)

Size And / Or loadings :

________ ☐☐☐ (50 51 52) UNIT ☐ (53)

________ ☐☐☐ (54 55 56) UNIT ☐ (57)

________ ☐☐☐ (58 59 60) UNIT ☐ (61)

Capital Cost ________ $ ☐☐☐ (62 63 64) 10X ☐ (65)

Land Value ________ $ ☐☐☐ (66 67 68) 10X ☐ (69)

Operating Costs ________ $/yr. ☐☐☐ (70 71 72) 10X ☐ (73)

Efficiency, % ☐☐ (74 75) On Basis Of CODE ☐ (76)

NO. OF CARDS 7 ☐ (77) SAME AS CARD 6 (78–79) END OF CARD 7 (80)

INDUSTRIAL WASTE TREATMENT PRACTICES DATA FORM

CARDS 8 CHARACTERISTICS OF SLUDGES

SAME AS CARD 7
1 17

Sludge Source No. ☐☐ Of ☐☐ Sludge Sources In Plant
18 19 20 21

Total Of Sludges In Plant ☐ Calculated As An Average
22

Quantity Lbs. Per Day ☐☐☐☐ x 10X ☐
23 24 25 26 27

Description Of Sludge:

____

____

____

____

____

____

____ CODE ☐☐☐☐
28 29 30 31

Treatment Of Sludge:

____

____

____

____ CODE ☐☐☐☐
32 33 34 35

Disposal Of Sludge:

____

____

____

____ CODE ☐☐☐☐
36 37 38 39

Capital Cost ______________________ $ ☐☐☐ ☐
40 41 42 43

Land Value ______________________ $ ☐☐☐ ☐
44 45 46 47

Operating Costs ______________________ $/yr ☐☐☐ ☐
48 49 50 51

Ultimate Disposal ☐ Satisfactory ☐ Marginal ☐ Unsatisfactory ☐
52 53 54 55

NO. OF CARDS 8 ☐ SAME AS CARD 7 END OF CARD 8
77 78 79 80

INDUSTRIAL WASTE TREATMENT PRACTICES DATA FORM

CARDS 9 APERTURE CARDS

SAME AS CARD 8
1 17

FIRST CARD 9

T R E A T M E N T P R A C T I C E S D A T A F O R M
18 46

APERTURE CODE ☐☐☐ NO. OF CARDS 9 ☐
50 51 52 77

ADD. CARDS 8

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐
18 46

APERTURE CODE ☐☐☐ NO. OF CARDS 9 ☐
50 51 52 77

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐
18 46

APERTURE CODE ☐☐☐ NO. OF CARDS 9 ☐
50 51 52 77

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐
18 46

APERTURE CODE ☐☐☐ NO. OF CARDS 9 ☐
50 51 52 77

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐
18 46

APERTURE CODE ☐☐☐ NO. OF CARDS 9 ☐
50 51 52 77

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐
18 46

APERTURE CODE ☐☐☐ NO. OF CARDS 9 ☐
50 51 52 77

ALL CARDS 9

SAME AS CARD 8 END OF CARD 9
78 79 80

APPENDIX B

ORGANIC CHEMICALS INDUSTRY SURVEY DATA

Plant Number	Critical Pollutant	Efficiency	Capital Cost Per 1000 GPD	Operating Cost Per 1000 GPD	Capital Cost Per Ton/Year	Operating Cost Per Ton/Yr.	Wastewater GPD/Ton/Yr.
1	Oil	-	-	229.75	-	0.50	2.18
1	All	100	-	729.17	-	-	-
1	All	100	-	365.39	-	-	-
1	BOD	85	-	-	-	-	-
1	BOD	85	-	-	-	-	-
1	All	100	-	-	-	-	-
* 2	All	98	193.51	11.24	4.08	0.24	21.08
2	All	100	187.50	6.25	-	-	-
2	All	100	156.25	6.25	-	-	-
3	CN	95	3,666.67	-	-	-	-
3	CN	95	25,000.00	6,000.00	-	-	-
* 4	COD	95	357.56	46.51	4.39	.57	12.28
4	COD	95	600.00	80.00	-	-	-
4	Oil	95	11.90	0.00	-	0.00	-
* 5	All	100	119.05	625.00	0.69	3.62	5.79
* 6	BOD	91	225.00	18.00	0.63	0.05	2.81
7	Oil	-	-	-	-	-	-
* 8	Oil	75	75.00	(42.97)	0.27	(0.15)	3.55
8	Acidity	99	330.00	(275.00)	-	-	-
8	Oil	75	18.52	27.78	-	-	-
8	Oil	-	7.81	(109.38)	-	-	-
9	Suspended Solids	90	16.98	-	-	-	-
*10	Suspended Solids	98	25,353.80	(1,048.22)	397.33	(16.43)	15.67
*11	BOD	85	697.39	78.95	401.52	45.45	575.76
11	Oil	98	190.00	-	-	-	-
11	Oil	-	50.00	-	-	-	-
11	Suspended Solids	75	163.16	-	-	-	-
11	BOD	85	205.26	-	-	-	-
*12	BOD	90	1,595.74	377.06	750.00	177.50	470.00
12	Oil	-	185.11	12.77	-	-	-
12	Color	50	379.79	311.70	-	-	-
12	Oil	-	329.79	47.87	-	-	-

(Continued)

Plant Number	Critical Pollutant	Efficiency	Capital Cost Per 1000 GPD	Operating Cost Per 1000 GPD	Capital Cost Per Ton/Year	Operating Cost Per Ton/Yr.	Wastewater GPD/Ton/Yr.
12	Oil	-	85.11	5.32	-	-	-
*13	All	100	1,160.00	48.00	644.44	26.67	555.56
13	Oil	-	65.00	2.00	-	-	-
13	Oil	-	81.00	34.00	-	-	-
13	BOD	35	48.00	4.00	-	-	-
13	All	100	860.00	4.00	-	-	-
13	Color	85	296.00	94.00	-	-	-
*14	BOD	91	736.98	64.87	3.93	0.34	5.20
14	All	100	7,700.00	520.00	-	-	-
14	BOD	90	677.97	61.02	-	-	-
14	Oil	20	22.88	-	-	-	-
14	Suspended Solids	85	34.75	-	-	-	-
14	Oil	-	33.90	-	-	-	-
14	BOD	95	-	-	-	-	-
14	Oil	-	-	-	-	-	-
*15	BOD	85	326.53	32.31	2.67	0.26	8.19
15	Oil	-	8.23	-	-	-	-
15	BOD	85	102.04	-	-	-	-
15	Oil	-	36.12	-	-	-	-
*16	BOD	95	48.07	15.17	1.42	0.45	29.47
*17	All	100	2,206.66	399.30	8.40	1.52	3.81
17	All	100	26,363.60	8,000.00	-	-	-
17	All	100	1,732.14	250.00	-	-	-
*18	BOD	95	1,891.89	421.62	-	-	-
18	Oil	-	383.78	-	-	-	-
18	Oil	-	675.68	-	-	-	-
18	Oil	-	124.32	-	-	-	-
*19	All	100	1,760.00	200.00	33.85	3.85	19.23
*20	All	15	1,464.09	101.29	39.75	2.75	27.15
20	All	5	940.00	20.00	-	-	-
20	All	100	7,558.14	1,046.51	-	-	-
*21	Oil	-	127.69	13.85	1.66	0.18	13.00

(Continued)

Plant Number	Critical Pollutant	Efficiency	Capital Cost Per 1000 GPD	Operating Cost Per 1000 GPD	Capital Cost Per Ton/Year	Operating Cost Per Ton/Yr.	Wastewater GPD/Ton/Yr.
22	All	100	132.14	1,232.14	-	-	-
22	TOC	20	676.92	-	-	-	-
*23	BOD	11	159.50	-	1.18	-	7.41
23	Oil	-	48.21	-	-	-	-
23	Oil	-	49.17	-	-	-	-
23	Oil	-	40.00	-	-	-	-
23	Oil	-	50.00	-	-	-	-
23	BOD	11	56.00	-	-	-	-
*24	BOD	50	290.27	-	4.19	-	14.43
24	BOD	98	440.00	26.67	-	-	-
24	Oil	-	280.44	-	-	-	-
25	BOD	95	3,672.43	335.71	-	-	-
25	Oil	-	63.07	-	-	-	-
25	Oil	-	178.03	-	-	-	-
25	SS	95	289.93	-	-	-	-
25	Oil	-	467.96	-	-	-	-
25	SS	98	335.71	-	-	-	-
26	BOD	80	146.36	16.00	-	-	-
26	Oil	-	60.00	-	-	-	-
26	Oil	-	20.00	-	-	-	-
26	Oil	-	212.50	-	-	-	-
26	Oil	-	60.00	-	-	-	-
*27	BOD	90	115.88	-	3.13	-	26.97
27	BOD	91	1,395.35	-	-	-	-
27	Oil	95	-	-	-	-	-
28	BOD	87	296.56	56.25	-	-	-
28	BOD	20	151.56	-	-	-	-
28	BOD	87	145.00	-	-	-	-
29	BOD	85	84.03	-	-	-	-
29	Oil	-	31.02	4.63	-	-	-
29	BOD	85	26.16	-	-	-	-
29	Oil	-	26.85	-	-	-	-
30	BOD	80	250.00	26.19	-	-	-

(Continued)

Plant Number	Critical Pollutant	Efficiency	Capital Cost Per 1000 GPD	Operating Cost Per 1000 GPD	Capital Cost Per Ton/Year	Operating Cost Per Ton/Yr.	Wastewater GPD/Ton/Yr.
30	Oil	-	-	-	-	-	-
30	Oil	-	-	19.04	-	-	-
30	BOD	80	226.19	7.14	-	-	-
31	Oil	90	84.22	-	-	-	-
31	All	100	1,186.05	-	-	-	-
31	Oil	-	-	-	-	-	-
*32	BOD	91	850.00	265.00	3.40	1.06	4.00
*33	BOD	66	335.71	47.62	1.93	0.27	5.75
34	BOD	98	801.89	216.04	-	-	-
*35	BOD	98	1,207.48	-	2.09	-	1.73
35	All	100	30,000.00	-	-	-	-
35	BOD	98	607.64	-	-	-	-
37	BOD	85	-	-	-	-	-

NOTES:

All plant numbers with an asterisk indicates information covering the entire plant.

All cost figures in parentheses indicate profit.

The following abbreviations are used.

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
TOC	Total Organic Carbon
SS	Suspended Solids

APPENDIX C

PETROCHEMICAL INDUSTRY PRODUCT PROFILES

Source of Data:

Chemical Profiles, Oil, Paint and Drug Reporter

Future Chemical Growth Patterns, R. N. Rickles

Chemical Growth, Vol. I, Aromatics, R. Strobaugh,
Gulf Publishing Company

ACETALDEHYDE

Present Producers	Capacity*
Celanese, Bay City, Texas	210
Celanese, Bishop, Texas	200
Celanese, Clear Lake, Texas	195
Celanese, Pampa, Texas	10
Eastman, Kingsport, Tennessee	200
Hercules, Parlin, New Jersey	250
Publicker, Philadelphia, Pa.	80
Union Carbide, various locations	650
Others	22
Total	1832

*million pounds

Production

1968: 1,600 million pounds
1973: 1,950 million pounds

Uses

Acetic acid and anhydride, n-butanol, 2-ethylhexanol

Process

Acetaldehyde is produced from the:

1) Hydration of acetylene

$$C_2H_2 + H_2O \longrightarrow CH_3CHO$$

2) Oxidation of Ethyl Alcohol

$$C_2H_5OH + \frac{1}{2}O_2 \longrightarrow CH_3CHO + H_2O$$

3) Oxidation of lower paraffin (propane and butane)

4) Oxidation of ethylene via the Wacker process

$$CH_2CH_2 + PdCl_2 + H_2O \longrightarrow CH_3CHO + Pd + 2HCl$$

$$Pd + 2HCl = \frac{1}{2}O_2 \longrightarrow PdCl_2 + H_2O$$

The Wacker process is the only major process being installed today and it is anticipated that future expansions will be based on this route.

Waste Problems

A typical Wacker process discharges about 1200 gallons per ton of product. The composition of the waste stream is primarily chlorinated aldehydes with a COD in the order of 10,000 mg/l. This is based on a yield of 95%. The waste is difficult to treat biologically unless it is diluted with other waters. In addition, it is quite acid and runs around pH2. It is to be noted that several facilities handle these wastes by means of a deep well rather than by biological treatment.

Reduction in Waste Loading by Process Change

It is possible by means of a rather simple still design change to concentrate the waste stream so as to reduce the discharge to 150-200 gallons/ton of product. No reduction in organic loading is produced and this approach is only practiced in those cases where deep well disposal or incineration is planned. The process change costs about $50,000 in a typical 200,000,000 pounds/year facility.

The only possible means of reducing the organic load center around recovery and use of the chlorinated aldehydes, de-chlorination of the aldehydes or improvements in yield. The latter is where emphasis is placed. It is expected that the average yeild will reach 97% in 5 years thereby reducing organic loading by about 40%.

ACETIC ACID AND ANHYDRIDE

Acid Producers	Capacity*
Borden, Geismer, La.	100
Celanese, Bishop, Texas	200
Celanese, Pampa, Texas	500
Eastman, Kingsport, Tennessee	325
Hercules, Parlin, New Jersey	40
Publicker, Philadelphia, Pa.	80
Union Carbide, Brownsville, Texas	500
Union Carbide, S. Charleston, W. Va.	140
Union Carbide, Texas City, Texas	100
Total	1985

*million pounds/year does not include by product and fermentation acetic acid which amounts to 100,000,000 pounds.

Production

1968: 1,700 million pounds
1973: 2,500 million pounds

Uses

Cellulose acetate, vinyl acetate, acetic esters, chloroacetric acid

Process

Acetic acid is produced by:

1) oxidation of acetaldehyde

2) from ethanol

3) LPG oxidation (liquified petroleum gas)

4) from methanol and carbon monoxide

The most popular technique in use is the oxidation of acetaldehyde while production from ethanol is only of minor importance. The Reppe method, from methanol and CO, is the newest method (developed by BASF) and appears to be gaining favor in this country. In the future it is expected that processes based on acetaldehyde and methanol will predominate in the production of acetic acid and anhydride.

Waste Problems

LPG oxidation results in the production of substantial amounts of other acids such as formic and proponic which must be disposed of incineration, resale or by biological oxidation. Unfortunately, resale of these materials does not appear to be practical because the markets for these chemicals are quite limited. Waste flow for this system is in the order of 1000 gallons/ton of product and the organic concentrations are in excess of 30,000 mg/l. In some operations, the stream is neutralized (it usually runs at pH4) with caustic and the sodium salts of the acid are recovered. Treatment by any number of means are quite routine. Biological modes are quite adequate.

Oxidation of acetaldehyde also produces higher acids and other oxidized species in quantities somewhat less than produced by LPG oxidation. Water flows are of the same magnitude, but organic load is about 50% of the load generated by the oxidation of LPG.

In the Reppe process, about 80 pounds of organics (50% propionic acid and 50% higher organics) are produced in the liquid waste stream per ton of product. The liquid stream amounts to about 50 gallons per ton of product including drains.

Reduction in Waste Loading by Process Change

The changes in process do not appear to change the nature of the wastes generated by the production of acetic acid or the quantity of the waste. Further the amounts and character of the waste would not appear to create serious waste treatment problems or expenditures.

There will be improvements in the yield picture which will certainly assist in reducing the waste management problems, but it is not anticipated that any changes will radically change the waste situation.

ACETONE

Producers	Capacity*
Allied, Frankford, Pa.	150
Celanese, Bishop, Texas	35
Chevron, Richmond, Calif.	35
Clark, Blue Island, Illinois	30
Eastman, Kingsport, Tennessee	60
Enjay, Linden, New Jersey	110
Hercules, Gibbstown, New Jersey	30
Monsanto, Albin, Texas	75
Shell, Dominguez, Calif.	150
Shell, Houston, Texas	210
Shell, Norco, La.	100
Skelly, El Dorado, Kansas	30
Union Carbide Institute, W. Va.	120
Union Carbide, Bound Brook, N. J.	90
Union Carbide, Texas City, Texas	130
Union Carbide, Whiting, Indiana	120
Total	1475

*millions of pounds per year

Production

1968: 1.3 billion pounds
1973: 1.8 billion pounds

Uses

Methyl isobutyl ketone and carbinol, Methyl acrylate, bisphenol A, paint, lacquer and varnish solvent, cellulose acetate solvent.

Processes

Currently there are three major processes utilized for the production of acetone.

These are:

a) Dehydration of isopropanol

$(CH_3)_2\ CHOH \longrightarrow (CH_3)_2\ CO + H_2$

b) By product from the production of phenol from cumene

$(C_6H_5)\ (C_3H_7) + O_2 \longrightarrow C_6H_5OH + C_3H_6O$

c) Direct oxidation of propylene

$CH3CH = CH2 + \frac{1}{2}O2 \longrightarrow CH_3COCH_3$

It is expected that a major portion of the acetone will continue to be produced from cumene as a phenol by product. It seems likely that direct oxidation of propylene will gain acendency relative to the production from isopropanol.

Waste Problems

The processes based on isopropanol dehydration produce about 200-250 pounds of organics per ton of product. These consist of still bottoms (0.5% organics) principally. The nature of the organics is somewhat complex but may include acetone, unreacted alcohol and higher polymeric species. The amount of waste water depends in part upon the amount of cooling water utilized as well as the frequency of equipment cleaning. It is also important to note that the process utilizes either metallic copper or zinc acetate as a catalyst and catalyst cleanup could put significant amount of these materials into the water course or to treatment.

The wastes produced during the production of phenol and acetone from cumene will be discussed in the section on phenol.

Direct oxidation results in a yield of 93% which in turn produces less than 80 pounds per ton of product as an organic load within the system. Water load varies, but exclusive of cooling water amounts to about 750 gal/ton. The regeneration of the cupric chloride catalyst may also cause difficulty.

Waste Reduction by Process Change

The utilization of direct oxidation will greatly reduce the amount of organic discharge both when directly compared with isopropanol based processes and when considering the additional wastes generated by the production of isopropanol. Therein lies another key factor in the evaluation of trends in the chemical industry. The desire to reduce the number of processing steps both to reduce direct operating costs and to increase yield generally results in greatly reduced waste loads.

It is possible through careful control and operation of the still to greatly reduce the amount of acetone in the still bottoms. These costs are generally minor relative to the value of the recovered acetone but must be the result of a concious management effort.

ACETYLENE

Producers	Capacity*
Diamond, Deep Park, Texas	40
Dow, Freeport, Texas	15
Monochem, Geismer, La.	165
Monsanto, Texas City, Texas	100
Rohm and Haas, Deep Park, Texas	35
Tenneco, Houston, Texas	100
Union Carbide, various locations	150
Total	650

*millions of pounds per year

Production

1968: 610 million pounds
1973: 630 million pounds

Uses

Vinyl chloride, vinyl acetate, neoprene, acrylates and acrylonitriles.

Processes

Acetylene is produced from two major sources in the U.S. About 50% of the acetylene is produced by the reaction of calcium carbide and water.

$CaC_2 + 2H_2O \longrightarrow C_2H_2 + Ca(OH)_2$

The second process involves the partial oxidation of natural gas.

$CH_4 + O_2 \longrightarrow CO_2 + H_2O$

$2CH_4 \longrightarrow C_2H_2 + H_2$

Other approaches involve the pyrolysis route as shown below is typified by the Wulff process,

$C_4H_{10} \longrightarrow C_2H_2 + C_2H_4 + CO$

$C_2H_4 \longrightarrow C_2H_2 + H_2$

$2CH_4 \longrightarrow C_2H_2 + H_2$

It is unlikely that many changes will occur with regard to the production of acetylene in this country unless someone comes up with a process with greatly reduced production costs which would have the effect of bringing the cost of acetylene close to the cost of ethylene. If this does not occur, it will not be possible for acetylene to maintain many markets in face of ethylene.

Waste Problems

The major waste associated with the production of acetylene from calcium carbide is the lime slurry residue.

However, the hydrocarbon processes do generate large amounts of water borne wastes. These quantities are quite variable and depend upon the feedstock, the degree of pyrolysis, the ratio of acetylene to olefins produced, etc.

The wastes arise from the gas cooler and the scrubbing of the higher concentrations of tars and oils and are quite difficult to treat in conventional treatment facilities.

Waste Reduction by Process Change

The key factor in waste management in the production of acetylene from hydrocarbons centers around the control of the cracking furnaces to maximize the production of valuable products. Improvements in the difficult-to-optimize reaction system are a key to the success of the process but quite difficult to improve. Since efficiencies have been known to run as low as 40-50%, it is not surprising that efficiency improvements is vital to the process. This is the key process change which can be implemented and returns from this operation are tremendous relative to production of costs. Further, recoveries of waste products in burnable form is also vital to the effective operation of the unit. In some operations, a solvent is used to recover the acetylene. Solvent losses may be significant and add to the dimensions of the waste treatment problem. Careful selection of the solvent, and improved design of the vacuum stripper should assist in reducing solvent losses.

ACRYLATES

Producers	Capacity*
Celanese, Pampa, Texas	45
Dow, Freeport, Texas	40
Goodrich, Calvert City, Kentucky	5
Minnesota Mining, St. Paul, Minn.	3
Rohm and Haas, Deer Park, N. J.	200 (a)
Union Carbide, Taft, La.	200 (b)
Union Carbide, Institute, W. Va.	50 (b)
Total	543

*million of pounds/year

(a) 120 million pounds to be added by 1969
(b) Taft facility completed by October, 1968;
Institute may be retired

Production

1968: 240 million pounds
1973: 400 million pounds

Uses

Paint latices, textiles, acrylic acid specialties, acrylic fibers.

Processes

The major process involved in the production of acrylates is the oxidation of acetaldehyde.

Waste Problems

Waste streams associated with this operation are generally composed of polymerization and degradation.

The flow rate is about 1500 gallons per ton of product with organic concentrations of about 10-20,000 mg/1. Yields in this process could be improved thereby reducing waste problems. A number of water waste streams and gas vents are often incinerated. Extension of this practice would reduce the amount of waste waters to be treated.

Waste Reduction by Process Change

Considerable efforts are underway to improve yields and this should result in lower waste water discharges.

AMMONIA

Major Ammonia Producers (600 TPD and up)

Producer	Capacity*
Air Products, Michoud, La.	600
Allied, Geismar, La.	1000
Allied, Hopewell, Va.	1000
Apple River, E. Dubuque, Illinois	700
American, Texas City, Texas	2100
American Cyanamid, Avondale, La.	1000
Arkla, Helena, Arkansas	600
Borden, Geismar, La.	900
Central Farmers, Donaldsonville, La.	1000
Chevron, Pascagoula, Miss.	1500
Coastal, Yazoo, Miss.	1000
Collier, Brea, California	750
Collier, Cook Inlet, Alaska	1500
Commercial Solvents, Sterlington, La.	1000
Consumers, Fort Dodge, Iowa	600
Continental, Blytheville, Arkansas	1000
duPont, Beaumont, Texas	1000
duPont, Belle, W. Va.	1000
Farmland, Dodge City, Kansas	600
First Mississippi, Donaldsonville, La.	1000
First Nitrogen, Donaldsonville, La.	1000
Gulf, Borger, Texas	1000
Mobil, Beaumont, Texas	750
Olin-Mathieson, Lake Charles, La.	1400
Phillips, Beatrice, Neb.	600
Sinclair, Ft. Madison, Iowa	1000
Terra, Port Neal, Iowa	600
U.S. Steel, Clairton, Pa.	1150
Valley Nitrogen, El Centro, Calif.	600
Total	29,550

*Tons/Day

Production

1968: 14,200,000 tons/year
1973: 20,000,000 tons/year

Uses

Fertilizers, area, nitric acid

Processes

Ammonia is produced from synthesis gas ($CO + H_2$) under conditions of relatively high temperatures and high pressure. Synthesis gas is produced primarily by the steam reformation of natural gas or other hydrocarbon sources as shown below:

$$CH_4 + H_2O \longrightarrow CO + 3H_2$$

During the reformation, air is added to provide additional energy for the endothermic reformation reaction. The air also provides N_2 for ammonia formation. The CO is converted to CO_2 and removed. Conversion to ammonia then takes place:

$$N_2 + 3H_2 \longrightarrow CO_2 + 2H_2$$

The major change in processing technology which has taken place recently has been the development of large single train ammonia plants of capacities as high as 1500 tons/day. This trend is expected to continue. These plants produce large point source concentrations of ammonia and carbon dioxide. However, these large streams have made the recovery of ammonia practical.

Waste Problems

The major streams arising from an ammonia plant are process condensate and site drains. The flow and waste produce loads are as listed below:

Flow (Gals/Ton of product)	300
NH_3 (Lbs/Ton)	0.1
NH_4HCO_3 (Lbs/Ton)	0.1
MEA (Monoethanolamine) (Lbs/Ton)	0.2
CO_2 (Lbs/Ton)	0.7

Normal practice in this county is to either strip the ammonia or to release the discharge untreated although it is anticipated that this practice cannot be continued in the future.

Waste Reduction by Process Change

It is possible to reduce the ammonia loss by some 60% by adjusting pH and airstripping. About 0.1 pounds of NaOH is added per ton of product. This is normal practice. It is possible to remove greater amounts of NH_3 (90-95%) by increasing the air flow to perhaps 500-1000 scf/gal. Following the normal industry practice a cost of the stripper and condenser is about $60,000 for a 1200 ton/day plant. The cost of removing additional quantities of ammonia have not been calculated since no plants practicing this extreme approach have ever been built.

BENZENE

Producers	Capacity*
Allied, Winnie, Texas	4
Amoco, Texas City, Texas	15
Ashland, N. Tonawanda, N. Y.	10
Ashland, Catlettsburg, Ky.	20
Atlantic-Richfield, Wilmington, Calif.	18
Atlas, Shreveport, La.	10
Chevron, El Segundo, Calif.	25
Chevron, Richmond, Calif.	10
Continental, Lake Charles, La.	6
Continental, Ponca City, Okla.	6
Cosden, Big Spring, Texas	9
Crown Central, Houston, Texas	38
Dow, Bay City, Mich.	20
Dow, Freeport, Texas	30
Enjay, Baton Rouge, La.	24
Enjay, Baytown, Texas	55
Gulf, Philadelphia, Pa.	27
Gulf, Port Arthur, Texas	32
Hess, Corpus Christi, Texas	30
Leonard, Mt. Pleasant, Mich.	3
Marathon, Texas City, Texas	6
Mobil, Beaumont, Texas	30
Monsanto, Alvin, Texas	65
Phillips, Sweeny, Texas	22
Pontiac, Corpus Christi, Texas	9
Shell, Houston, Texas	31
Shell, Odessa, Texas	20
Shell, Wilmington, Calif.	15
Shell, Wood River, Illinois	30

Producers	Capacity*
Signal, Houston, Texas	22
South Hampton, Silsbee, Texas	6
Sun, Marcus Hook, Pa.	15
Sunray DX, Tulsa, Oklahoma	22
Suntide, Corpus Christi, Texas	25
Tenneco, Chalmette, La.	15
Texaco, Port Arthur, Texas	30
Union Carbide, S. Charleston, W. Va.	10
Union Atlantic, Nederland, Texas	18
Union Oil, Lemont, Illinois	22
Vickers, Potwin, Kansas	3
Total from Petroleum Feedstocks	809
Total from 18 Cokeoven Producers and 3 Tar Distillers	142
Grand Total	951
Cities Service, Lake Charles, La.	55
Coastal States, Corpus Christi, Texas	6
Gulf, Port Arthur, Texas	25
Southwestern, Corpus Christi, Texas	6
Texaco, Port Arthur, Texas	15
Total announced new capacity	107
Grand Total, all U.S. Capacity	1058

*millions of gallons/year

Production

1968: 900 million gallons
1973: 1350 million gallons

Uses

Styrene, phenol, cyclohexane, detergent alkylate, aniline, Maleic acid DDT

Processes

About 60% of U.S. benzene is produced by recovery (together with toluene and xylenes) from refinery reformers while an additional 20% is produced from the dealkylatron of toluene. Coal tar, coke oven light oils and ethylene drip oils account for the remainder. It is expected that refinery based benzene will grow more rapidly than other sources. Naphthalene is similar.

Waste Sources

The major sources of waste water in the recovery of benzene, xylenes and toluene from refinery reformate are two-fold. First, cooling waters tend to pick up between 50-200 ppm of COD in the form of aromatics because of heat exchanger leaks. The quantity and quality of waste water arising from this source will depend upon the cooling system and will in general be associated with other cooling waters.

The aromatics are separated from the paraffins by extraction with aqueous diethylene glycol. Discarding of this solvent stream in order to control impurity buildup results in a waste stream containing aromatics and diethylene glycol. Here improvements in stripper design and careful control of blowdown from the solvent cycle will assist in greatly reducing waste water discharges. Aside from cooling waters, there are no significant sources of waste waters in the Hydrodealkylation of toluene.

Waste Reduction by Process Change

This control is possible primarily by 1) close maintenance of heat exchangers, 2) yield improvements, and 3) stripper design.

BUTADIENE

Producers	Capacity*
Chevron, El Segundo, Calif.	16,000
Copolymer, Baton Rouge, La.	60,000
Dow, Freeport, Texas	45,000
El Paso, Odessa, Texas	45,000
Enjay, Baton Rouge, La.	75,000
Enjay, Baytown, Texas	33,000
Firestone, Orange, Texas	110,000
Goodrich-Gulf, Port Neches, Texas	160,000
Mobil, Beaumont, Texas	25,000
Monsanto, Alvin, Texas	50,000
PCI (Cities Service), Lake Charles, La.	80,000
Petro-Tex, Houston, Texas	275,000
Phillips, Borger, Texas	112,000
Shell, Torrance, Calif.	70,000
Sinclair, Channelview, Texas	121,000
Texas-U.S., Port Neches, Texas	160,000
Tidewater, Delaware City, Del.	10,000
UCC, Seadrift, Texas; Ponce, P.R.	105,000
Total	1,577,000

*Tons per year

Production

1968:	1.50 million tons
1973:	1.80 million tons

Uses

Styrene-butadiene rubber, polybutadiene rubber, adiponitrile, nitrile rubber, S B and A-B-S plastics

Processes

Butadiene is produced from three major sources:

1. dehydrogenation of n butylenes
2. dehydrogenation of n butane
3. as a by-product of ethylene production

It is anticipated that by-product production will increase rapidly because of the expected rapid increase in ethylene production expected.

Waste Problems

Waste flows from butadiene production facilities amount to some 100 gals/ton of product with waste compositions as follows (taken from one source only):

pH	8-9
TOC	100-200 mg/l
filtered COD	250-375 mg/l
suspended solids	200-500 mg/l
total solids	3000-4000 mg/l (sulfates and chlorides principally)

Waste Reduction Through Process Modification

Little information is available regarding possible process modifications.

BUTANOL

Producers	Capacity*
Celanese, Bishop, Texas	125
Continental Oil, Westlake, La.	5
Dow-Badische, Freeport, Texas	15
Eastman, Longview, Texas	60
Shell Chemical, Houston, Texas	50
Union Carbide, various locations	240
Total	495

*millions of pounds annually

Production

1968: 500 million pounds
1973: 620 million pounds

Uses

Glycolethers and amine resins, solvent, n butyl acetate, plasticizers

Process

Butanol is produced by the oxidation of LPG or other petroleum streams.

Waste Problems

Waste streams arise primarily from the still discharges following the separation of various products together with wastes resulting from catalyst and vessel cleanouts. Cooling waters also contain considerable wastes. Waste waters discharged amount to several hundred gallons per ton of product while organic discharges amount to 100-300 pounds/ton of product.

Waste Reduction by Process Change

The waste problems of this process involve the low efficiency and rather drastic conditions under which the reaction takes place. Improvements in yields and improvement in still efficiencies would improve the situation. Further provisions can be made for the collection and direct incinerations of still bottoms, vessel cleanout wastes, etc., without contamination of the waste waters.

A number of waste streams may be either sent to additional strippers or vented to gas burners. The costs of such controls amount to some $250,000-$500,000 for an 80 million pound/year plant and will reduce the waste load by 25-50%.

CARBON MONOXIDE AND HYDROGEN (SYNTHESIS GAS)

See Ammonia

CARBON TETRACHLORIDE AND OTHER CHLORINATED HYDROCARBONS

Carbon Tetrachloride:

Producers	Capacity*
Allied, Moundsville, W. Va.	8
Diamond, Painesville, Ohio	35
Dow, Freeport, Texas	130
Dow, Pittsburg, Calif.	30
Dow, Plaquemine, La.	20
FMC-Allied, S. Charleston, W. Va.	200
Stauffer, Le Moyne, Alabama	85
Stauffer, Louisville, Ky.	70
Stauffer, Niagara Falls, N. Y.	125
Vulcan, Wichita, Kansas	25
Total	728

*millions of pounds per year

Chloroform:

Producers	Capacity*
Allied, Moundsville, W. Va.	30
Diamond, Belle, W. Va.	20
Dow, Freeport, Texas	75
Dow, Pittsburg, Calif.	1
DuPont, Niagara Falls, N. Y.	15
Stauffer, Louisville, Ky.	75
Vulcan, Newark, N. J.	6
Vulcan, Wichita, Kansas	16
Total	238

*millions of pounds per year

Methylene Chloride:

Producers	Capacity*
Allied, Moundsville, W. Va.	50
Diamond, Belle, W. Va.	30
Dow, Freeport, Texas	85
Dow, Pittsburg, Calif.	20
DuPont, Niagara Falls, N. Y.	60
Stauffer, Louisville, Ky.	70
Vulcan, Newark, N. J.	20
Vulcan, Wichita, Kansas	20
Total	355

*millions of pounds per year

Methyl Chloride:

Producers	Capacity*
Allied, Moundsville, W. Va.	17
Ancon, Lake Charles, La.	100
Dow, Freeport, Texas	100
Dow, Pittsburg, Calif.	20
Dow Corning, Midland, Michigan	10
Dow Corning, Carrollton, Kentucky	20
DuPont, Niagara Falls, N. Y.	76
Ethyl, Baton Rouge, La.	75
General Electric, Waterford, N. Y.	24
Vulcan, Newark, N. J.	2
Total	454

*million of pounds per year

Production

	CCl_4	$CHCl_3$	CH_2Cl_2	CH_3Cl
1968:	700	200	265	240
1973:	900	300	400	370

Use

Fluorocarbons, solvent

Process

These chlorinated methanes are produced by the reaction of chlorine with methane and then are separated by fractionation. Carbon tetrachloride is also produced by the reaction of hydrogen chloride with carbon bisulfide.

Waste Problems

The major waste stream results from the production of hydrogen chloride as a by-product of the reaction.

Waste Reduction by Process Change

The main need is for routes to the economic recovery of chlorine from hydrogen chloride or through the reuse of hydrogen chloride. A number of new oxychlorination processes have recently been developed which enable the user to utilize hydrogen chloride together with chlorine in a balanced facility. As an example, for the production of carbon tetrachloride:

$$CH_4 + 2HCl_2 \longrightarrow CCl_4 + 4HCl$$

$$CH_4 + 4HCl + O_2 \longrightarrow CCl_4 + 2H_2O$$

This approach eliminates the problem of hydrogen chloride but it does produce about 60 gallons of waste water per ton of product which will contain minor amounts of chlorinated methanes and HCl. Further, these reactions often have an intermediate step involving copper chloride and small amounts of this catalyst will be released to the waste water. Insufficient data is available to predict relative waste loads and economics. This is anticipated that process changes will substantially eliminate the HCl being generated in these operations.

CELLULOSE ACETATE

Producers	Capacity*
Celanese, various locations	450
DuPont, Waynesboro, Va.	60
Eastman, Kingsport, Tenn.	215
FMC, Meadville, Pa.	25
Total	750

Production

1968: 740 million pounds
1973: 850 million pounds

Uses

Fibers, cigarette filters, plastics

Processes

Reaction of wood, pulp with acetic acid and anhydride to produce triacetate, hydrolysis to procude diacetate

Waste Problems

Major waste sources arise from the stills used to recover acetic acid and acetone and other solvents. In addition, considerable amounts of degraded celluloses as well as phosphates (used as catalyst) and sulfuric acid (from spills). About 3-3.5 gallons of waste waters are generated with a solid loading of 200 mg/l and a BOD of 1-3000 mg/l depending upon the relationship of flake to fiber production.

Waste Reduction Through Process Change

There are numerous opportunities for waste reduction in cellulose acetate production. Among these are the following:

1. Recovery and reuse of CA fines
2. Careful pH control in acetone stills
3. Control of vessel cleanout and acid spills
4. Improved operation of acetone and acetic acid stills
   Use of additional stills to improve recovery
5. Higher yields on cellulose (wood pulp)

CYCLOHEXANE

Producers	Capacity*
Ashland, Catlettsburg, Ky.	30
Atlantic Richfield, Wilmington, Calif.	15
Commonwealth-Shell, Puerto Rico	30
Continental, Ponca City, Okla.	80
Continental, Lake Charles, La.	
Cosden, Big Springs, Texas	8
DuPont, Belle, W. Va.	15
DuPont, Orange, Texas	15

*millions of gallons per year

Producers	Capacity*
Eastman, Longview, Texas	3
Enjay, Baytown, Texas	40
Gulf, Port Arthur, Texas	33
Phillips, Borger, Texas	47
Phillips, Sweeny, Texas	53
Phillips, Puerto Rico	40
Pontiac, Corpus Christi, Texas	12
Signal, Houston, Texas	17
South Hampton, Silsberg, Texas	3
Texaco, Port Arthur, Texas	40
Union Oil, Smith's Bluff, Texas	33
Total	514

*millions of gallons per year

Production

1968: 310 million gallons
1973: 570 million gallons

Uses

Nylon 66, Nylon 6

Processes

About 30% of the cyclohexane produced in this country is produced from the fractionation of petroleum. The remainder is produced by the catalytic hydrogenation of benzene. This latter process will account for some 85% of the cyclohexane produced in the U. S. after 1970.

Waste Problems

Outside of spills the only major source of water is the cooling water which amounts to 200-2000 gallons/ton of cyclohexane and which may contain 50-200 mg/l of COD. In aromatics extraction, there are two major sources of waste water the extract water washing which contains aromatic hydrocarbons and the wastes from solvent regeneration which contains appropriate solvents. Both wastes may be minimized by the use of stripping columns.

No discussion of cyclohexane recovery from petroleum fractions is included because this more properly fits in a discussion of petroleum refineries.

Waste Reduction by Process Change

No foreseeable changes in process will have any significant impact upon waste water discharges except for the replacement of once-through cooling with cooling towers. However, once-through cooling is generally not utilized in cyclohexane facilities.

CUMENE

Producers	Capacity*
Amoco, Texas City, Texas	50
Ashland, Catlettsburg, Ky.	300
Chevron, Richmond, Calif.	80
Clark, Blue Island, Illinois	100
Coastal States, Corpus Christi, Texas	100
Dow, Midland, Michigan	10
Gulf, Philadelphia, Pa.	400
Gulf, Port Arthur, Texas	300
Hercules, Gibbstown, New Jersey	60
Marathon Oil, Corpus Christi, Texas	125
Monsanto, Alvin, Texas	130
Shell, Houston, Texas	80
Skelly, El Dorado, Kansas	80
Sunray DX, Corpus Christi, Texas	125
Texaco, Westville, N. J.	140
Total	2220

*millions of pounds/year

Production

1968: 1.2 billion pounds
1973: 2.2 billion pounds

Uses

Phenol, acetone, a-methylstyrene

Process

The process for the production of cumene involves the reaction of benzene with propylene in a phosphoric acid catalyzed alkylation. No significant change in this technology is anticipated in near future.

Waste Problems

The principal waste streams from the manufacture of cumene are the process slops and the "cumene" bottoms which are a result of the recovery of cumene from the general process stream. This stream contains some 1-4% of the product stream. The quantity of water carrying the wastes depends largely upon the use of propane to control bed temperature.

Waste Reduction Through Process Change

Careful temperature control through propane injection may reduce the amount of byproducts and reduce the amount of water required in the tower to control this highly exothermic reaction.

ETHANOL

Producer	Capacity*
Synthetic (Ethylene)	
Enjay, Baton Rouge, La.	60
Eastman, Longview, Texas	25
Publicker, Philadelphia, Pa.	25
Shell, Houston, Texas	40
Union Carbide, S. Charleston, W. Va.	60
Union Carbide, Texas City, Texas	100
USI, Tuscola, Illinois	53

*millions of wine gallons annually, 190 proof alcohol

Producer	Capacity*
Other Industrial	
Ga-Pacific, Bellingham, Wash.	
Hercules, Hopewell, Va.	
Publicker, Philadelphia, Pa., other	20
Total	383

*millions of wine gallons annually, 190 proof alcohol

Production

1968: 299 million gallons
1973: 330 million gallons

Uses

Acetaldehyde, solvent, other chemicals

Process

Two processes are in use to produce ethanol from ethylene. The first, called the ethyl hydrogen sulfate route follows the following equation:

$$3C_2H_4 + 2H_2SO_4 \longrightarrow C_2H_5HSO_4 + (C_2H_5)_2SO_4$$

$$C_2H_5HSO_4 + (C_2H_5)_2SO_4 \longrightarrow 3C_2H_5OH + 2H_2SO_4$$

Ethyl ether is a byproduct.

The second is the Shell or direct hydration process and involves the temperature and pressure hydration over a phosphoric acid catalyst:

$$C_2H_4 + H_2O \longrightarrow C_2H_5OH$$

Waste Sources

The ethyl hydrogen sulfate has numerous waste sources. These include slops from the recovery and reconcentration of sulfuric acid (0.05 lb/lb of product) and the discharge of a waste caustic stream containing alcohol, ether and waste products from the alcohol scrubber. This stream may amount to several hundred gallons per ton of product and contain 1-3000 mg/l of COD at a high (11+) pH. An additional stream results from the recycling column which removes the heavy ends, and is an aqueous stream of perhaps 10-30 gals/ton of product and contains about 5000 mg/l of COD.

The direct hydration process involves considerably less waste. The major stream would result from the separation of the product ethanol from the process bottoms and may amount to 30-60 pounds of COD/ton of product.

Waste Reduction Through Process Change

It is possible to minimize the waste products by careful control of the use of sulfuric acid in the process and as is often the case, in the use of acid and alkali, the avoidance of leaks and spills. Additional stripping capacity and improved yields would also reduce waste product loads.

ETHYL BENZENE AND STYRENE

Producers (Styrene)	Capacity*
Amoco, Texas City, Texas	300
Cosden, Big Spring, Texas	100
Cos-Mar, Carville, La.	500
Dow, Freeport, Texas	550
Dow, Midland, Michigan	350
El Paso, Odessa, Texas	120
Enjay, Baytown, Texas	150
Foster Grant, Baton Rouge, La.	200
Marbon, Baytown, Texas	125
Monsanto, Alvin, Texas	40
Monsanto, Texas City, Texas	750
Shell, Torrance, Calif.	240
Sinclair-Koppers, Houston, Texas	70
Sinclair-Koppers, Kobuta, Pa.	270

*millions of pounds annually

Producers (Styrene)	Capacity*
Sinclair-Koppers, Port Arthur, Texas	150
Signal, Houston, Texas	35
Sunray DX, Corpus Christi, Texas	80
Suntide, Corpus Christi, Texas	75
Tenneco, Chalmette, La.	22
Union Carbide, Institute, W. Va.	130
Union Carbide, Seadrift, Texas	300
Total	3991

*millions of pounds annually

Production (Styrene)

1968: 3.5 billion pounds
1973: 5.0 billion pounds

Uses

Polystyrene, Rubber modified polystyrene, Styrene-butadiene copolymer, ABS, SAN plastics, Styrene-butadrene elastomer

Processes

About 10% of the ethyl benzene is obtained by fractionation of petroleum streams. The dominant route is via alkylation of benzene with ethylene. This is expected to continue in this fashion in the future. There are two alternative routes to ethyl benzene by alkylation. One involves the use of high purity ethylene while the other involves the use of low concentration ethylene. It is expected that the latter will become more prominent in the future.

Styrene is produced from ethyl benzene by the high temperature dehydrogenation of the ethyl benzene.

Waste Problems

A number of waste streams arise from the alkylation of benzene with high concentration ethylene. Among these are the caustic and water washing streams used to wash the crude alkylate which contain 5-10,000 mg/l of tars and other polymers together with significant amounts of ethyl benzene and benzene. The overheads from the benzene drying column may contain minor amounts of benzene. The residue from the PEB (polyethyl benzenes) column contains tars and polymers formed during the process. The total organic burden is in the order of 30-70 pounds/ton of product.

The process utilizing low concentration ethylene produces primarily a waste stream containing polymers and tars and amount to 50-100 pounds of organics per ton of product.

The styrene producing process condenses a water-styrene-ethyl benzene mixture and the water leaving this step containing oils as well as ethyl benzene and styrene.

Waste Reduction Through Process Change

Design of gas washers which improve contact conditions is one key to the reduction of waste waters coming from this process (high concentration). A larger benzene drying column will reduce benzene losses from this system. The tars and polymers produced from the final separator could be incinerated rather than sent to a waste water system.

ETHYLENE DICHLORIDE, VINYL CHLORIDE AND POLYVINYL CHLORIDE

Producers (Vinyl chloride)	Capacity*
Allied, Moundsville, W. Va.	500
American Chemical, Watson, Calif.	170
Conoco-Stauffer, Lake Charles, La.	600
Cumberland Calvert, Calvert City, Ky.	100
Diamond, Deer Park, Texas	100
Dow, Freeport, Texas; Plaquemine, La.	1000
Ethyl, Baton Rouge, La.; Houston, Texas	300
General Tire, Ashtabula, Ohio	75
Goodrich, Calvert City, Ky.	800
Goodrich, Niagara Falls, N. Y.	40
Goodyear, Niagara Falls, N. Y.	70
Monochem, Geismer, La.	250
Monsanto, Texas City, Texas	150

Producers (Vinyl chloride)	Capacity*
PPG, Lake Charles, La.	300
Tenneco, Houston, Texas	200
Union Carbide, S. Charleston, W. Va.	340
Union Carbide, Texas City, Texas	
Wyandotte, Geismer, La.	150
Total	5150

*millions of pounds/year

Production

1968: 2.7 billion pounds
1973: 4.0 billion pounds

Uses

PVC

Processes

There are several major routes to vinylchloride. Acetylene based processes employ the use of hydrogen chloride in a direct addition in acetylene

$C_2H_2 + HCl \rightarrow C_2H_3Cl$

Ethylene processes involve direct chlorination plus dehydrochlorination

$C_2H_4 + Cl \longrightarrow C_2H_4Cl_2$ (ethylene dichloride)

$C_2H_4Cl_2 \longrightarrow C_2H_3Cl + HCl$

A newer approach involves oxychlorination and permits the reuse of the HCl generated during dehydro chlorination (copper chloride is the catalyst).

$C_2H_4 + \frac{1}{2}O_2 + 2HCl \longrightarrow C_2H_4Cl_2 + H_2O$

It is expected that all vinyl chloride in the country will be produced by a balanced chlorination-oxychlorination approach in the future.

Polyvinyl chloride is polymerized directly from vinyl chloride by a mode of different approaches.

Waste Problems

The vinyl chloride facility generates a waste stream containing about 8 gallons/ton of product and containing minor amounts of organics (0.01 lbs/ton) with significant amounts of NaCl, $FeCl_3$, NaOH and $NaClO_3$.

The waste stream from the PVC operation is about 2000 gallons/ton of product and has a COD of 1200-1500 mg/l.

Waste Reduction Through Process Change

The advent of oxychlorination has made a major reduction in waste problems in the production of vinyl chloride. Waste problems are quite minor and little promise of change exists. Only minor pressure exists for the reduction in waste loadings from the PVC operation although changes in polymerization techniques may effect changes.

ETHYLENE

Producers	Capacity*
Allied-Wyandotte, Geismar, La.	500
American Can-Skelly, Clinton, Iowa	400
Atlantic, Watson, Calif.	100
Continental Oil, Lake Charles, La.	400
Dow, various locations	1920
DuPont, Orange, Texas	800
El Paso-Rexall, Odessa, Texas	290

Producers	Capacity*
Enjay, various locations	1265
Goodrich, Calvert City, Ky.	250
Gulf, various locations	825
Jefferson, Port Neches, Texas	450
Koppers, Kobuta, Pa.	35
Mobil, Beaumont, Texas	450
Monsanto, various locations	600
National Distillers, Tuscola, Illinois	320
Olin Mathieson, Brandenburg, Ky.	90
Petroleum Chemicals, Lake Charles, La.	360
Phillips, Sweeny, Texas	550
Phillips-Houston Natural Gas, Sweeny, Texas	550
Shell, various locations	845
Sinclair-Koppers, Houston, Texas	500
Sun Olin, N. Claymont, Del.	125
Texas Eastman, Longview, Texas	450
Union Carbide, various locations	3975
Total	16000

*millions of pounds per year

Production

1968: 12,500,000,000 pounds per year
1973: 19,000,000,000 pounds per year

Uses

Polyethylene, ethylene oxide, ethanol, styrene, vinylchloride

Processes

Ethylene is produced from ethane and propane, refinery off gas and other sources such as naphtha, gas oil, condensate. The first step involves cracking, then compression followed by purification. Ethylene production is an important source of propylene butadiene and aromatics.

Waste Problems

The major waste streams are:

a. blowdown from steam generation
b. coke and tar in the furnace
c. compressor water (oily)
d. spent caustic from acid gas scrubbing
e. water from dryers
f. green oil produced as a polymerization product during acetylene hydrogenation

Typical Quantities are:

Spent caustic - 15 gallons/ton of product containing 2.5% NaOH, 1.0% Na_2S and 6.6% ppm of phenols and 100-500 mg/l of COD.

Waste Reduction by Process Change

The process condensate stream may be reprocessed by being sent to a stripper and stripped by live steam. This will strip most of the non phenol contaminants and about 20-25% of phenol. If fresh feed is contacted with the process condensate, it is possible to strip out most of the phenol which is then sent with the feed to the cracking furnace. The phenol free waste water can then be steam stripped to remove residual volatile hydrocarbons. The water stream, free of contaminants may be reused in steam generation in the plant.

Studies are underway to recover the alkali values from the spent caustic. For the moment, sulfide oxidation is generally practiced to reduce the immediate oxygen demand of this stream.

Green oil is piped to plant fuel systems and burnt along with tar and other heavy polymer by-products.

ETHYLENE OXIDE

Producers (Ethylene Oxide)	Capacity*
Allied, Orange, Texas	40
Calcasieu, Lake Charles, La.	150
Dow, various locations	900
DuPont	300
Eastman, Longview, Texas	60
GAF, Linden, N. J.	70
Houston Chemical	80
Jefferson, Port Neches, Texas	750
Olin Mathieson, Brandenburg, Ky.	120
Shell Chemical, Norco, La.	150

Producers (Ethylene Oxide)	**Capacity***
Sun Olin, Marcus Hook, Pa.	100
Union Carbide, various locations	1700
Wyandotte, Geismer, La.	100
Total	4520

*millions of pounds per year

Production

1968: 3,000,000,000 pounds/year (Ethylene Oxide)
1973: 5,000,000,000 pounds/year

Use

Surfactants, ethanol amines, polyglycols, antifreeze, polyester fibers

Processes

The chlorohydrin method involves the reaction of chlorine water with ethylene to produce the chlorohydrin and HCl. This was then treated with bicarbonate to produce the glycol:

$$C_2H_4 + Cl_2 + H_2O \longrightarrow CH_2OH - CH_2Cl + HCl$$

$$CH_2OH - CH_2Cl + NaHCl \longrightarrow CH_2OH - CH_2OH + NaCl + CO_2$$

Ethylene oxide could be produced by adding caustic and rectifying the vapors

Direct oxidation of ethylene:

$$C_2H_4 + O_2 \longrightarrow C_2H_4O$$

is the process which is now widely practiced. Hydrolysis of the oxide produces the glycol. The product of various glycol ethers and glycols as by-products is quite common.

Waste Problems

The older chlorohydrin process produces great quantities of waste HCl which is usually lime neutralized as well as waste organic streams. The major waste stream is a lime slurry (about 2000 gallons/ton). It is not expected that any chlorohydrin plants will be built in the future.

Oxidation-hydration plants produce two major waste streams. One is produced at the rate of 1500 gallons/ton of product and is 0.1% organic. The other is produced at the rate of 150 gallons/ton of product and is 1% organic in one process. In a similar system, the total water flow was about 1000 gallons/ton of product with a concentration of 1-20,000 mg/1 COD. Both contain a mixture of oxide, glycol, polyglycols, etc.

Waste Reduction Through Process Change

It is possible through the addition of stripping columns and the addition of certain streams to cooling water systems to reduce the waste water discharge to 10% of the numbers cited above. The cost is in the order of $150-210,000 in a 50,000,000 pounds/year plant.

Waste Reduction by Process Change

Water wastes can be largely eliminated by reusing the dimethyl ether to produce additional formaldehyde and by reprocessing the scrubber waters and truck washings to produce additional formaldehyde.

ISOPROPANOL

Producers	Capacity*
Enjay, Baton Rouge, La.	680
Shell, Dominguez, Calif.	225
Shell, Houston, Texas	380
Union Carbide, Texas City, Texas	400
Union Carbide, Whiting, Indiana	275
Total	1960

*millions of pounds per year

Production

1968: 1750 million pounds
1973: 2250 million pounds

Uses

Acetone, solvent

Processes

Isopropanol is manufactured either by catalytic hydration of propylene:

$$CH_3 - CH - CH_2 + H_2O \longrightarrow CH_3CHOHCH_3$$

or by the reaction or sulfuric acid propylene similar to the ethanol reaction.

Waste Problems and Process Change

See Ethanol

FORMALDEHYDE

Producers	Capacity*
Allied	310
Borden	925
Celanese	950
Commercial Solvents	60
DuPont	900
GAF	100
Georgia Pacific	120
Gulf	115
Hercules	275
Hooker	90
Monsanto	400
Reichhold	212
Rohm and Haas	50
Tenneco	325
Trojan Powder	50
Union Carbide	150
Total	5042

*millions of pounds per year

Production

1968: 4.0 billion pounds
1973: 5.2 billion pounds

Uses

Phenolic resins, urea and melamine resins, ethylene glycol.

Process

Straight oxidation of methanol with air or oxygen. The major by-products are dimethyl ether and formic acid which amount to 150 pounds/ton of product.

Waste Problems

The major sources of waste are the scrubber waters and the dimethyl ether by-product. The total aqueous stream should not exceed 100 gallons/ton containing 1-5000 mg/l COD unless truck washing is practiced at the site.

METHANOL

Producers	Capacity*
Allied	26
Borden	160
Celanese	75
CSC	65
DuPont	380
Escambia	30
Gulf	9
Hercules	16
Monsanto-Tenneco	30
Rohm and Haas	22
Tenneco	76
Union Carbide	64
Total	943

*millions of gallons per year

Production

1968: 600 million gallons
1973: 900 million gallons

Uses

Formaldehyde, methyl esters, amines, solvent

Processes

The major process for the production of methanol involves the high pressure catalytic conversion of synthesis gas ($CO + H_2$) to methanol. Recently ICI has developed a low pressure process.

Waste Problems

Although little information is available on the lower pressure process only minor differences between waste streams would appear to exist. Major waste water streams are from slab and vessel wash downs together with bottoms from the methanol purification process. This amounts to 100-500 gallons/ton of product and contains some oils, methanol and higher boiling organics to the extent of several hundred mg/l.

Waste Reduction Through Process Change

More effective separations and better housekeeping can produce greatly reduced water flows. The dimethyl ether produced from this waste can be sent to a formaldehyde production facility for conversion into formaldehyde.

PHENOL

Producers	Capacity*
Allied	350
Chevron	50
Clark Oil	50
Dow	270
Hercules	50
Hooker	130
Monsanto	285
Reichhold	90
Shell	50
Skelly Oil	50
Union Carbide	575
Total	1950

*million pounds per year

Production

1968: 1500 million pounds
1973: 2200 million pounds

Uses

Phenolic resins, caprolactam, bisphenol-A, adipic acid

Processes

Phenol is made from cumene, from benzene by the Raschig process

$$C_6H_6 + HCl + \frac{1}{2}O_2 \longrightarrow C_6H_5Cl + H_2O$$

$$C_6H_5Cl + H_2O \longrightarrow C_6H_5OH + HCl$$

from benzene by the chlorobenzene route:

$$C_6H_6 + Cl_2 \longrightarrow C_6H_5Cl + HCl$$

$$C_6H_5Cl + 2NaOH \longrightarrow C_6H_5ONa + NaCl + H_2O$$

$$C_6H_5ONa + HCl \longrightarrow C_6H_5OH + NaCl$$

and by the sulfonation process from benzene:

$$C_6H_6 + H_2SO_4 \longrightarrow C_6H_5SO_3H + H_2O$$

$$2C_6H_5SO_3H + Na_2SO_3 \longrightarrow 2C_6H_5SO_3Na + SO_2 + H_2O(+Na_2SO_4)$$

$$C_6H_5SO_3Na + 2NaOH \longrightarrow C_6H_5ONa + Na_2SO_3 + H_2O$$

$$2C_6H_5ONa + SO_2 + H_2O \longrightarrow 2C_6H_5OH + Na_2SO_3(+Na_2SO_4)$$

Recently two new routes have been commercialized. One is Dow Chemical process which involves direct oxidation of toluene to benzoic acid and then oxidation of the benzoic acid to phenol in a single step.

It is anticipated that cumene based phenol will continue to hold a major share of the market. Furthermore, it is expected that the direct oxidation routes will also gain importance.

Waste Problems

In addition to quantities of wastewaters discharged from the separation of the phenol the less used processes all produce major quantities of inorganic containing aqueous wastes which create considerable difficulties relative to waste treatment. A typical 100,000,000 pound/year phenol plant based on cumene produces a stream of 200,000 gpd of waste water containing 13,200 mg/l of COD and 180 mg/l of phenol. Inorganics are produced at the following rates:

Sodium carbonate (5000 lbs/day); sodium formate (500 lbs/day); sodium bicarbonate (500 lbs/day) and sodium sulfate (22,000 lbs/day)

The waste production from the direct oxidation facility might be considerably less than the older process.

Waste Reduction Through Process Control

It is possible to reduce effluents by careful control of the process involved, recovery of the inorganics by crystallization, etc., and by solvent extraction of the phenol. It is also likely that as the sulfonation and chlorination approaches are reduced in importance the amount of waste generated per pounds of phenol produced will be greatly reduced.

POLYETHYLENE - HD

Producers	Capacity*
Allied, Baton Rouge, La.	150
Allied, Orange, Texas	25
Celanese, Pasadena, Texas	150
Chemplex, Clinton, Ia.	50
Dow, Freeport, Texas	50
Dow, Plaquemine, La.	50
DuPont, Orange, Texas	75
Gulf, Orange, Texas	100
Hercules, Parlin, N. J.	80
Monsanto, Texas City, Texas	50
National Petrochemicals, La Porte, Texas	125
Phillips, Pasadena, Texas	160
Sinclair-Koppers, Port Reading, N. J.	50
Union Carbide, Seadrift, Texas	125
Total	1230

*millions of pounds per year

Production

1968: 1200 million pounds
1973: 2000 million pounds

Uses

Blow molding, injection molding, film and sheet, wire and cable, pipe and conduit

Processes

Polyethylene is produced by the catalyzed polymerization of ethylene. High pressure processes use oxygen or peroxides for a catalyst while the low pressure processes (which produce high density products) use metal derived catalysts.

Waste Problems

About 400 gallons/ton of product of waste water is produced from these units and this flow has the following characteristics:

Suspended Solids	100 ppm
COD	200 mg/1

Waste Reduction by Process Changes

It is possible to greatly reduce the discharge of solids by improving the utilization of centrifuges and other separation equipment.

POLYETHYLENE - LD

Producers	Capacity*
Allied, Orange, Texas	25
Chemplex, Clinton, Iowa	100
Columbian Carbon, Lake Charles, La.	100
Dow, Freeport, Texas	170
Dow, Plaquemine, La.	130
DuPont, Orange, Texas	425
DuPont, Victoria, Texas	200
Eastman, Longview, Texas	175
Enjay, Baton Rouge, La.	200
Gulf, Cedar Bayou, Texas	200
Gulf, Orange, Texas	200
Monsanto, Texas City, Texas	130
National Distillers, Deer Park, Texas	300
National Distillers, Tuscola, Illinois	150
Rexall-El Paso, Odessa, Texas	250
Sinclair-Koppers, Port Arthur, Texas	125
Union Carbide, Seadrift, Texas	200
Union Carbide, S. Charleston, W. Va.	100
Union Carbide, Taft, La.	500
Union Carbide, Texas City, Texas	290
Union Carbide, Torrance, Calif.	80
Union Carbide, Whiting, Indiana	200
Total	4250

*millions of pounds per year

Production

1968: 2900 million pounds
1973: 4700 million pounds

Uses

Film and sheet, injection molding, extension coating, wire and cable

Processes

See Polytheylene-HD

Waste Problems

The waste stream which is primarily drains, amounts to 200 gpd/ton of product and contains 50-100 mg/l COD and 100 mg/l of oil.

Waste Reduction

See Polyethylene-HD

POLYSTYRENE

Producers	Capacity*
Amoco, Leominster, Mass; Medina, O; Torrance, Calif; Willow Sp., Ill.	120
Badische, Jamesburg, N. J.	25
Columbian, Hicksville, N. Y.	10
Cosden, Big Springs, Texas	120
Dow, Allyns Pt., Conn; Ironton, O; Midland, Mich; Torrance, Calif; Riverside, Mo.	610
Foster Grant, Leominster, Mass; Peru, Ill.	
Hammond, Worcester, Mass.	50
Monsanto, Addyston, O; Long Beach, Calif; Springfield, Mass.	300
Rexall, Holyoke, Mass; Santa Clara, Calif.	70
Richardson, West Haven, Conn.	30
Shell, Wallingford, Conn.	25
Sinclair-Koppers, Kobuta, Pa.	190

Producers	Capacity*
Solar, Leominster, Mass.	50
Union Carbide, Bound Brook, N. J.; Marietta, O.	165
Total	1865

*million pounds per year

Production

1968: 1.7 million tons
1973: 3.0 million tons

Uses

Molding, Blow extrusion

Processes

Polymerization with or without catalysts

Waste Problems

A typical plant produces a 600 gallons/ton of product with the following composition:

Styrene	3 ppm	
Benzoyl Peroxide	1400 ppm	
Tricalcium Phosphate	800 ppm	Ca
	2200 ppm	PO_4
Alkyl Aryl Sulfonate	80 ppm	
Suspended Solids	500 ppm	

Waste Reduction by Process Change

It is possible by cleaning up this stream to recover Benzoyl Peroxide for reuse. This scheme would cost less than $0.40/1000 gals. and would provide a completely closed system and eliminate almost all reuse.

PROPYLENE

Producers	Capacity*
Ashland, Catlettsburg, Ky.	130
Atlantic-Richfield, Watson, Calif.	230
Amoco, various locations	510
Chevron, El Segundo, Calif.	160
Cities Services, Lake Charles, La.	320
Clark, Blue Island, Ill.	70
Dow, various sites	440
DuPont, Orange, Texas	200
El Paso, Odessa, Texas	60
Enjay, various sites	1440
Goodrich, Calvert City, Ky.	90
Gulf, various sites	830
Jefferson, Port Neches, Texas	150
Marathon, Texas City, Texas	70
Mobil, Beaumont, Texas	520
Monsanto, various sites	360
Petroleum Chemicals, Lake Charles, La.	60
Phillips, Sweeney, Texas	180
Shell, various sites	630
Signal, Houston, Texas	90
Sinclair, Houston, Texas & Marcus Hook, Pa.	380
Sinclair-Koppers, Houston, Texas	100
Skelly, El Dorado, Kansas	90
Sohio, Lima, Ohio	110
Sun, Marcus Hook, Pa.	300
Suntide, Corpus Christi, Texas	70
Texaco, Westville, N. J.	140
Texas City Ref., Texas City, Texas	100
Texas Eastman, Longview, Texas	100
Tidewater-Air Products, Delaware City, Del.	250
Union Carbide, various sites	550
Union Oil, Los Angeles, Calif.	140
Total	8920

*millions of pounds per year

Production

1968: 7,000 million pounds per year
1973: 11,000 million pounds per year

Uses

Isopropanol, acrylonitrile, polypropylene, propylene oxide, heptene, cumene, glycerine

Processes

Propylene is produced together with ethylene and details may be obtained from the section on ethylene. However, the major portion of the propylene is produced as a by-product of gasoline product (over 85%). It is expected that the amount of propylene generated will increase as the demand for high octane low leaded gasolines increase.

Waste Reduction

See ethylene section

PROPYLENE OXIDE

Producers	Capacity*
Celanese, Bishop, Texas	10
Dow, Freeport, Texas	225
Dow, Midland, Mich.	25
Jefferson, Port Neches, Texas	120
Olin, Brandenburg, Ky.	80
Oxirane, Bayport, Texas	150
Union Carbide, S. Charleston, W. Va.	200
Wyandotte, Wyandotte, Mich.	160
Total	1020

*millions of pounds per year

Production

1968: 890 million pounds
1973: 1750 million pounds

Uses

Polypropoxyethers, propylene glycol, polypropylene glycol, dipropylene glycol

Process

See Ethylene Oxide section. Oxirane has developed a process based on the oxidation of acetaldehyde.

Waste

See Ethylene Oxide

TOLUENE

Producers	Capacity*
Amoco, Texas City, Texas	20
Ashland, North Tonawanda, N. Y., Catlettsburg, Ky.	20
Atlantic Richland, Wilmington, Calif.	24
Chevron, El Segundo, Calif; Richmond, Calif.	32
Cities Services, Lake Charles, La.	36
Coastal States, Corpus Christi, Texas	10
Cosden, Big Spring, Texas	15
Crown Central, Houston, Texas	10
Dow, Bay City, Mich.	17
Enjay, Baton Rouge, La.; Baytown, Texas	65
Gulf, Philadelphia, Pa; Port Arthur, Texas	20
Hess, Corpus Christi, Texas	18
Leonard, Mount Pleasant, Mich.	3
Marathon, Texas City, Texas	12
Mobil, Beaumont, Texas	25
Monsanto, Alvin, Texas	32
Pontiac, Corpus Christi, Texas	13
Shell, Houston, Texas; Odessa, Texas Wilmington, Calif; Wood River, Ill.	65
Signal, Houston, Texas	16
Sinclair, Houston, Texas; Marcus Hook, Pa.	26
South Hampton, Silsbee, Texas	6
Southwestern, Corpus Christi, Texas	10
Sun, Marcus Hook, Pa.	25
Sunray DX, Tulsa, Okla.	4
Suntide, Corpus Christi, Texas	13
Tenneco, Chalmette, La.	8
Texaco, Port Arthur, Texas	31
Union Carbide, S. Charleston, W. Va.	10
Union Oil-Atlantic, Nederland, Texas	20
Union Oil, Lemont, Ill.	10
Vickers, Potwin, Kansas	5
Total	620**

*millions of gallons per year

**also 65 million gallons from coke oven, tar distiller and styrene monomer operations

Production

1968: 610 million gallons
1973: 800 million gallons

Uses

Benzene, solvents, gasoline, TNT, Toluene diisocyanate, phenol

Process

Toluene is produced by extraction from refinery reformate as is benzene. For details see benzene.

UREA

Producers	Capacity*
Allied	320
American Cyanamid	150
Arkla	67
Armour	17
Best	20
Collier	50
Columbia Nitrogen	25
Cooperative Farmer	50
DuPont	205
Escambia	23
Farmers Chemical	30
Fel Tex	20
Grace	100
Gulf	90
Hawkeye	25
Hercules	60
Ketman	7
Miss. Chem	80
Mobile	5
Monsanto	80
Nipack	260
Nitrin	23
Olin	150
Phillips	8
Phillips Pacific	20
Premier	70
Shell	185
Solar	140
Southern Nitrogen	60
Sun Olin	75
Valley Nitron	35
Wycon	50
Total	1500

*thousands of tons

Production

1968: 2.3 million tons
1973: 3.7 million tons

Uses

Animal feed, fertilizer, plastics

Processes

All of the major processes involve the high pressure reaction of CO_2 and ammonia. There are about 10 variations of this scheme.

Waste Problems

Typical wastes amount to about 120 gallons/ton of product with the following composition:

	lbs/ton
NH_3	3.6
CO_2	0.6
Urea	0.8
Carbonate	0.1

Waste Reduction Through Process Change

It is normal practice to remove about 50% of the ammonia by airstripping after adjusting pH with alkali. Recently two new processes have been developed which strip the ammonia and carbonate by contacting with either NH_3 or CO_2 and sending the overload directly to the reactor. This approach is expected to reduce ammonia losses by 50% or more with a more drastic effect on carbonate. These also involve operation of the reaction at a lower temperature.

XYLENES

Producers	Ortho Capacity*	Para Capacity*
Amoco	---	200
Chevron	130	536
Cities Service	120	---
Coastal	42	6
Commonwealth	70	---
Cosden	---	6

Crown Central	19	---
Enjay	175	210
Hercor	---	100
Hess	45	---
Shell	---	100
Signal	---	15
Sinclair	80	215
Sunray DX	30	165
Tenneco	25	100
Total	736	1547

*millions of gallons per year

Production

	Ortho	Para
1968	500	750
1973	750	1800

Uses

Phthalic anhydride, polyesters

Process

Mixed xylenes are recovered primarily from refinery streams (see benzene and ethyl benzene). It is separated out with ethyl benzene and isomerization is carried out to increase the yield of para xylene. A separation scheme involves crystallization to separate out the various streams.

Waste Problems

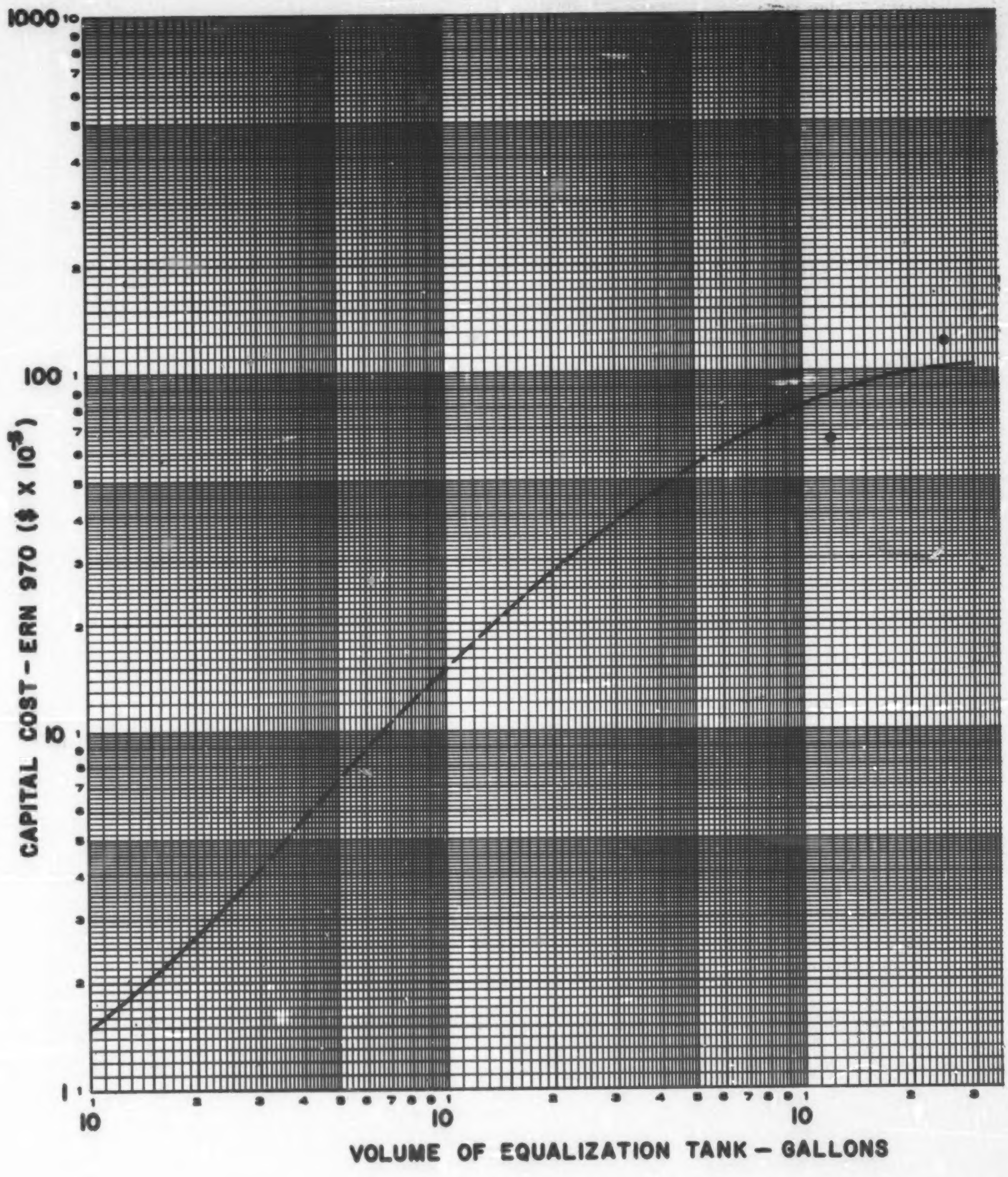
Sludge from the crystallizer as well as bottoms, drains, etc., amount to perhaps 100-500 gallons/ton of product with an organic content of 3-5,000 mg/1.

APPENDIX D

COSTS OF UNIT WASTEWATER TREATMENT PRACTICES

CAPITAL COST RELATIONSHIP
EQUALIZATION

Figure 1-D



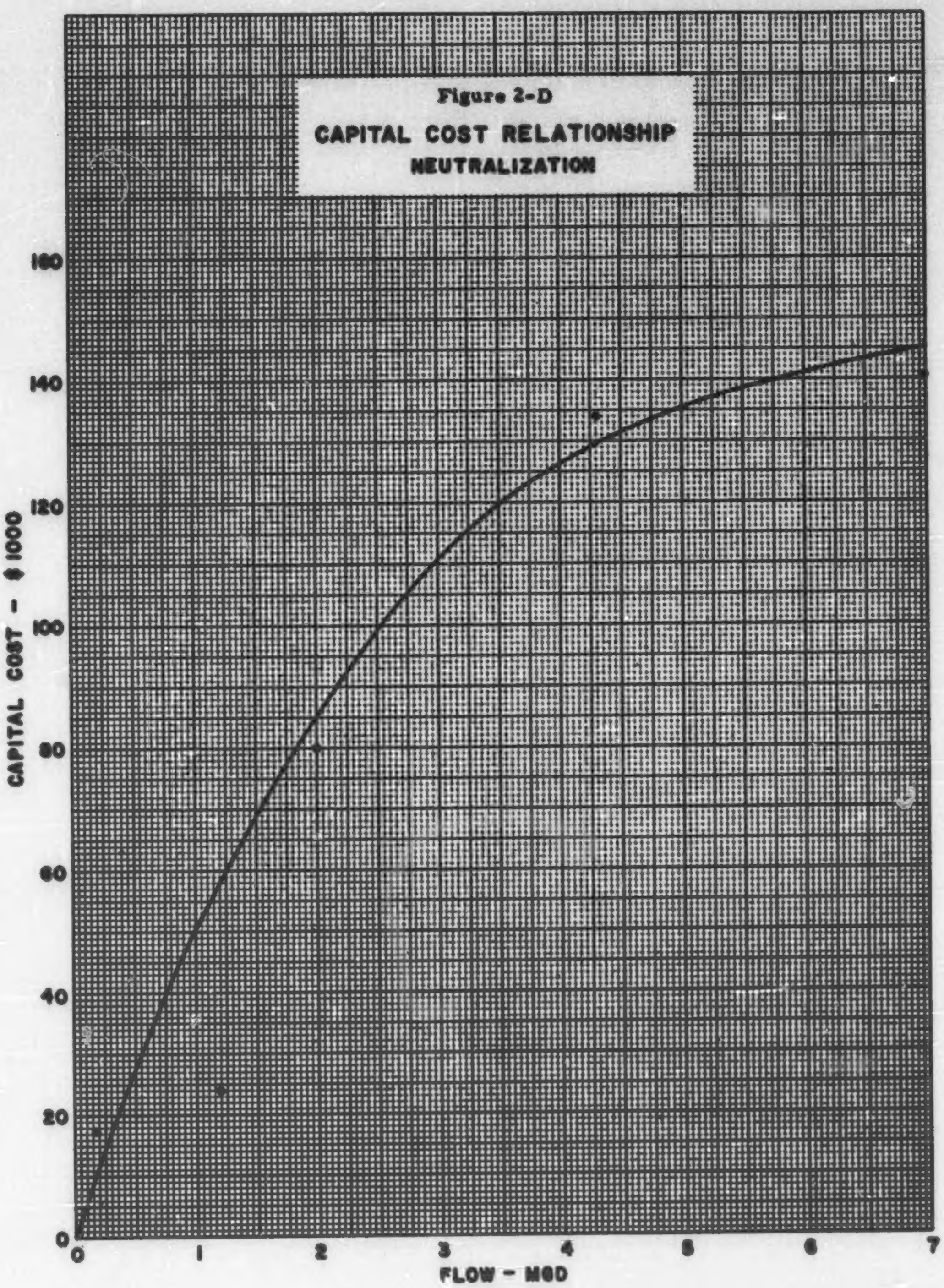


Figure 2-D

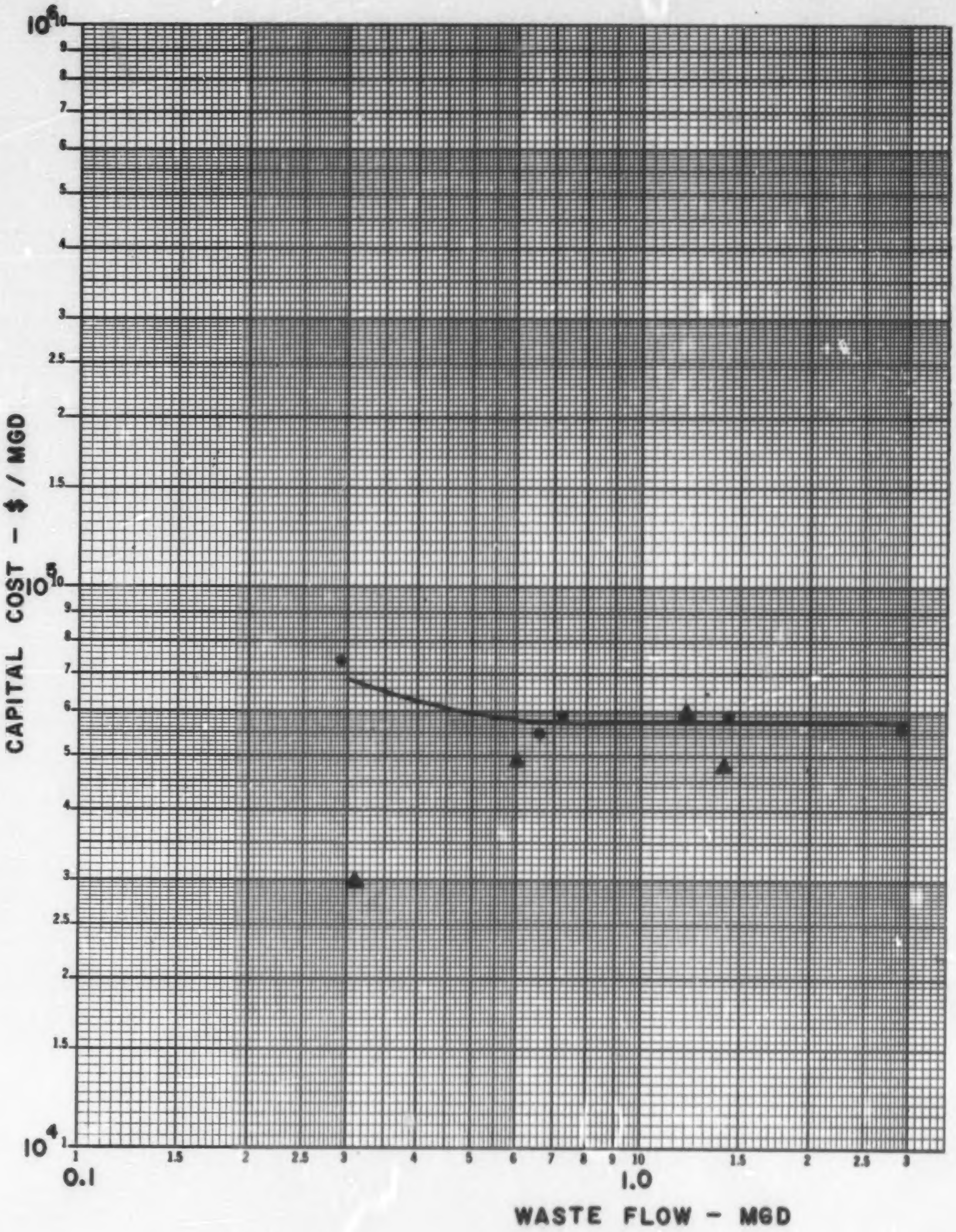
CAPITAL COST RELATIONSHIP

NEUTRALIZATION

CAPITAL COST RELATIONSHIP

OIL SEPARATION

Figure 3-D



CAPITAL COST RELATIONSHIP

PRIMARY SEDIMENTATION

Figure 4-D

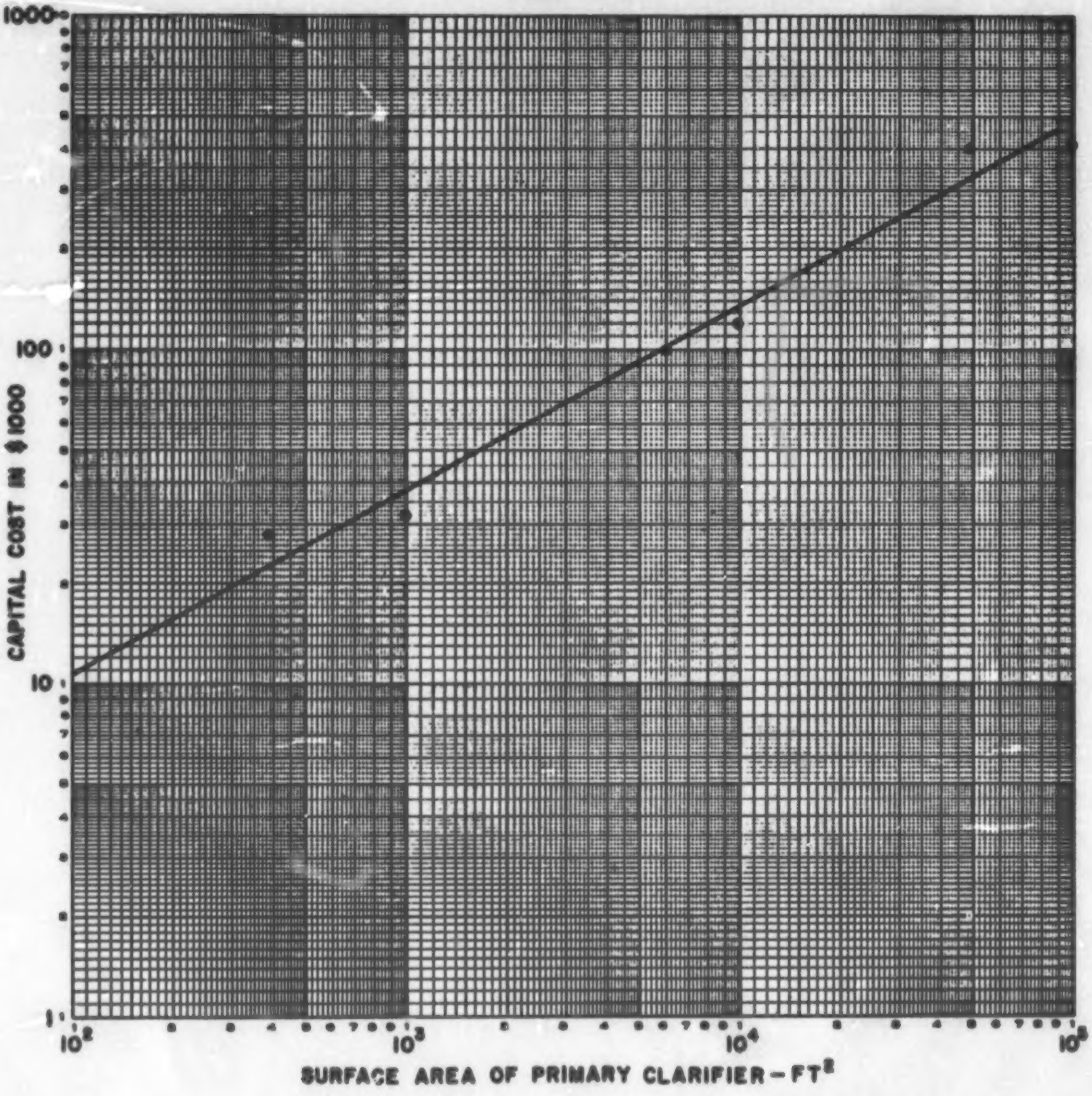
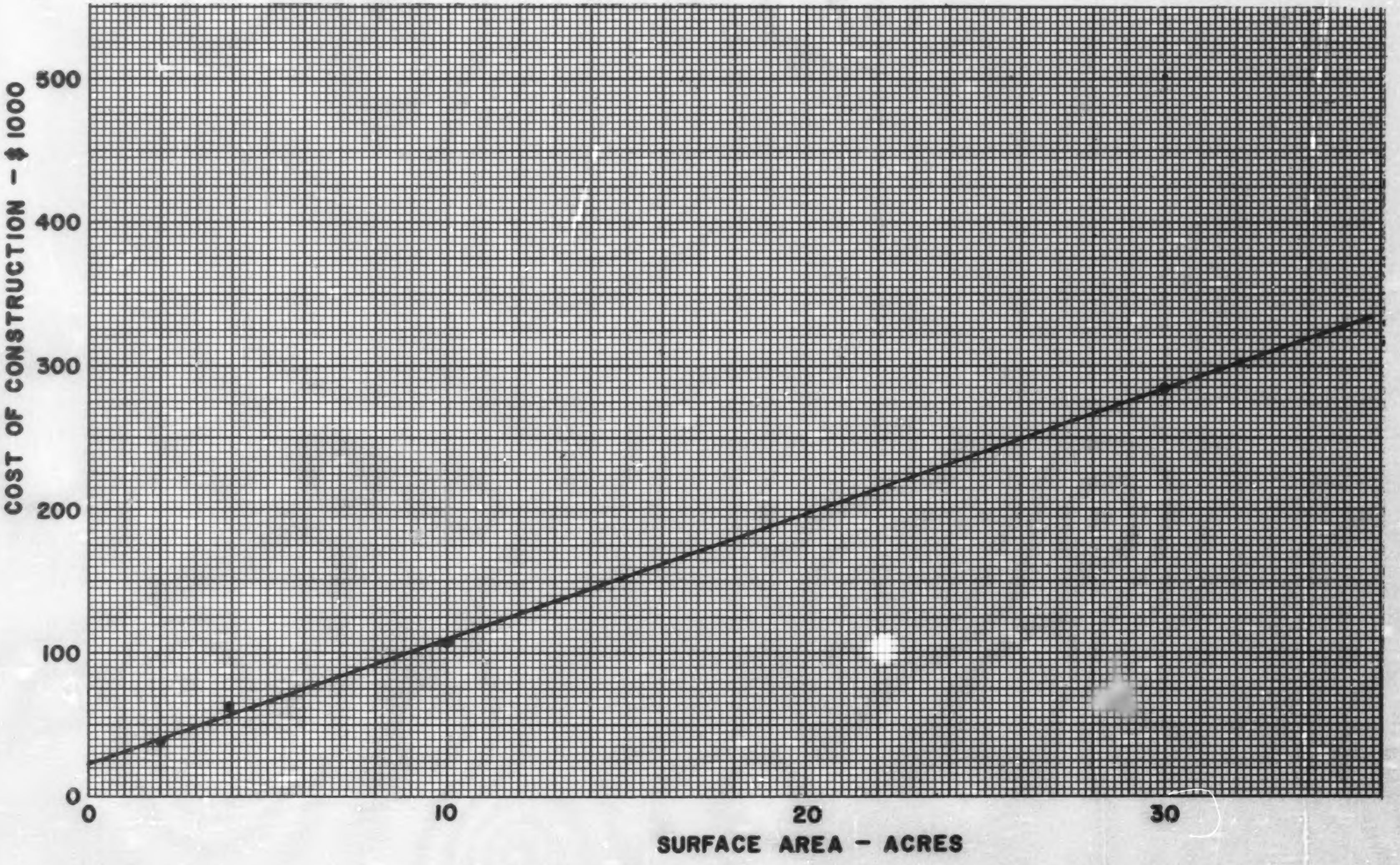


Figure 5-D

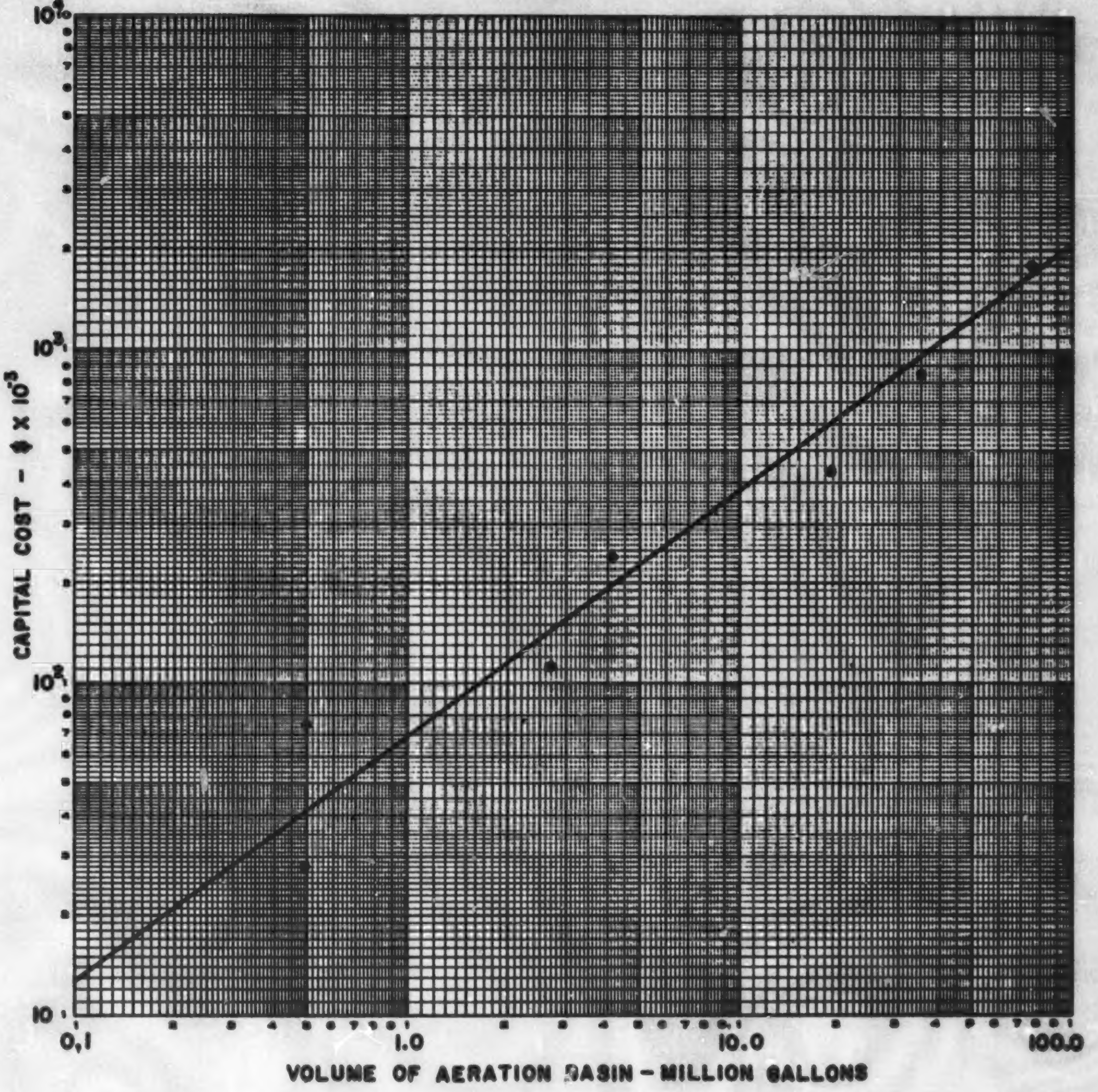
CAPITAL COST RELATIONSHIP
LAGOONS



CAPITAL COST RELATIONSHIP

AERATED LAGOON

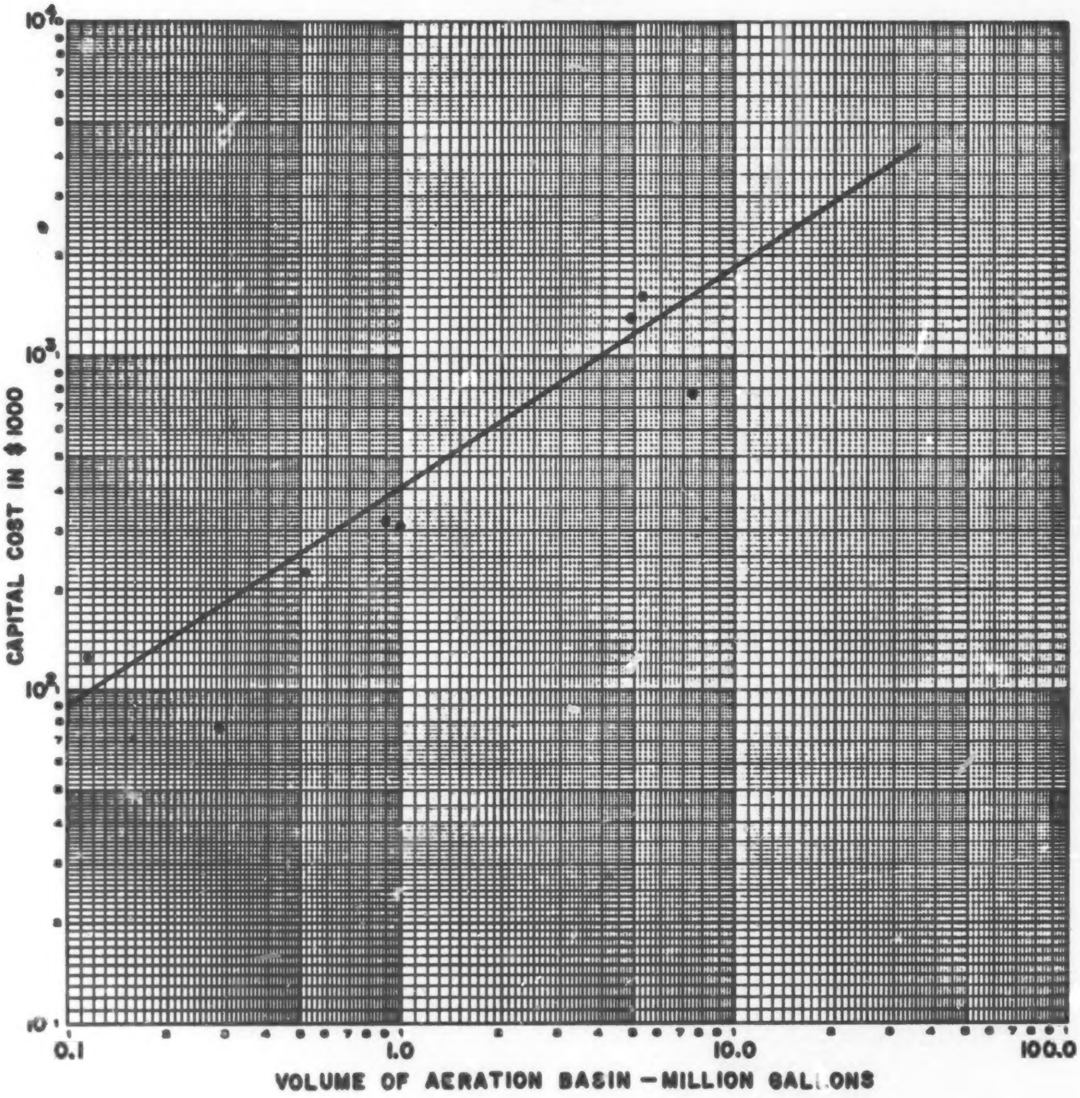
Figure 6-D



CAPITAL COST RELATIONSHIP

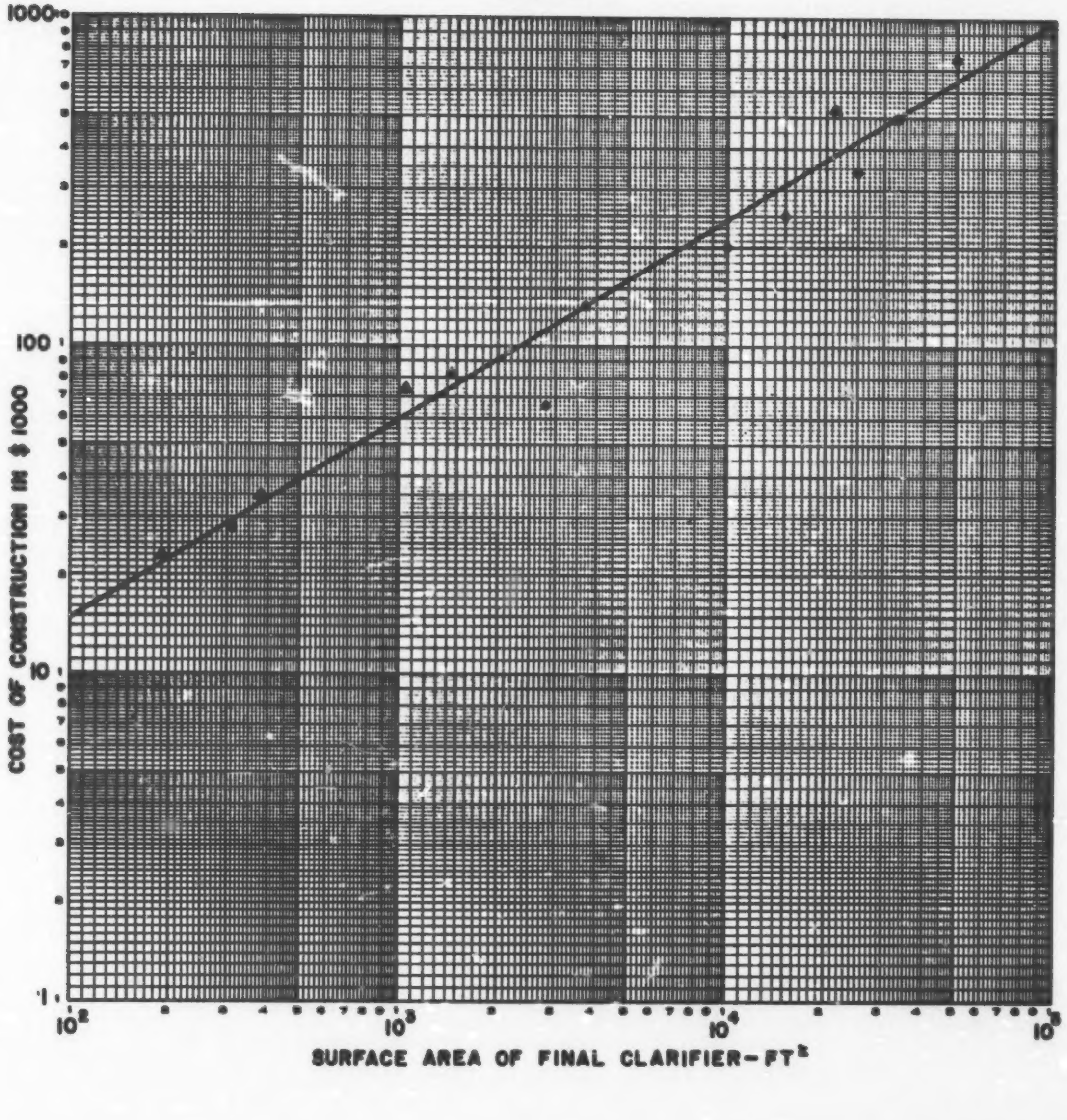
AERATION BASIN

Figure 7-D



CAPITAL COST RELATIONSHIP
FINAL CLARIFIERS

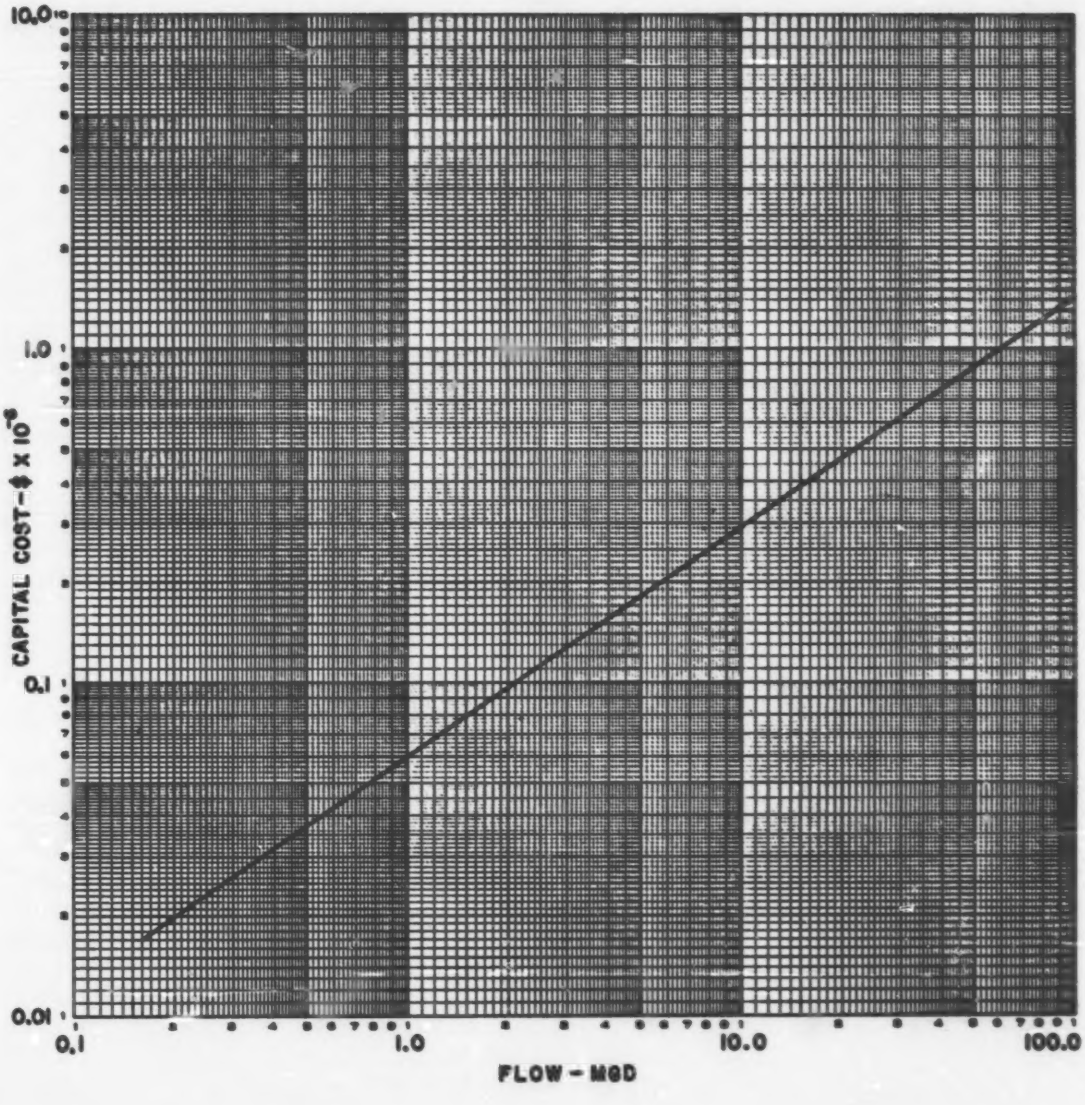
Figure 8-D



CAPITAL COST RELATIONSHIP

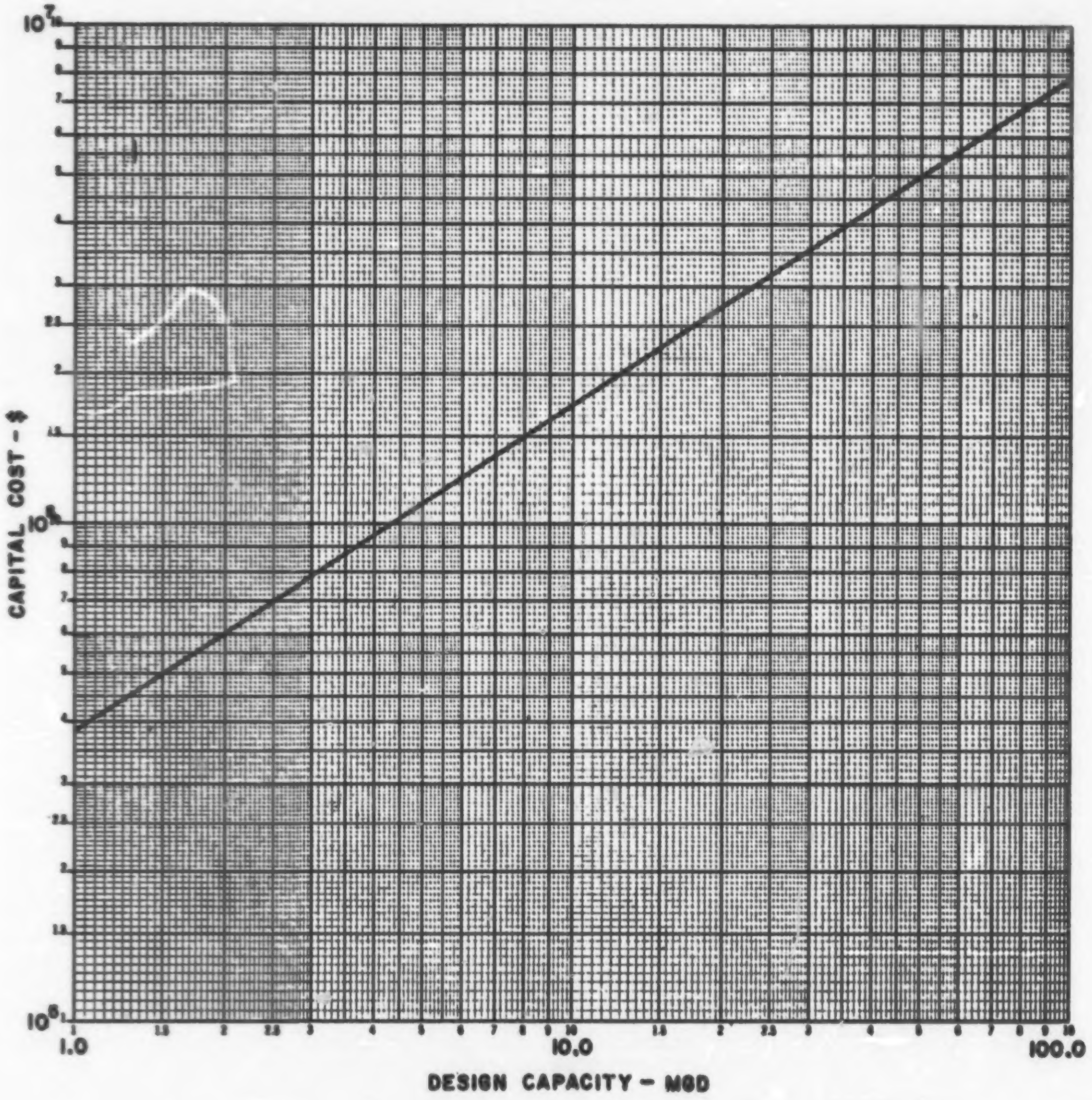
FILTRATION

Figure 9-D



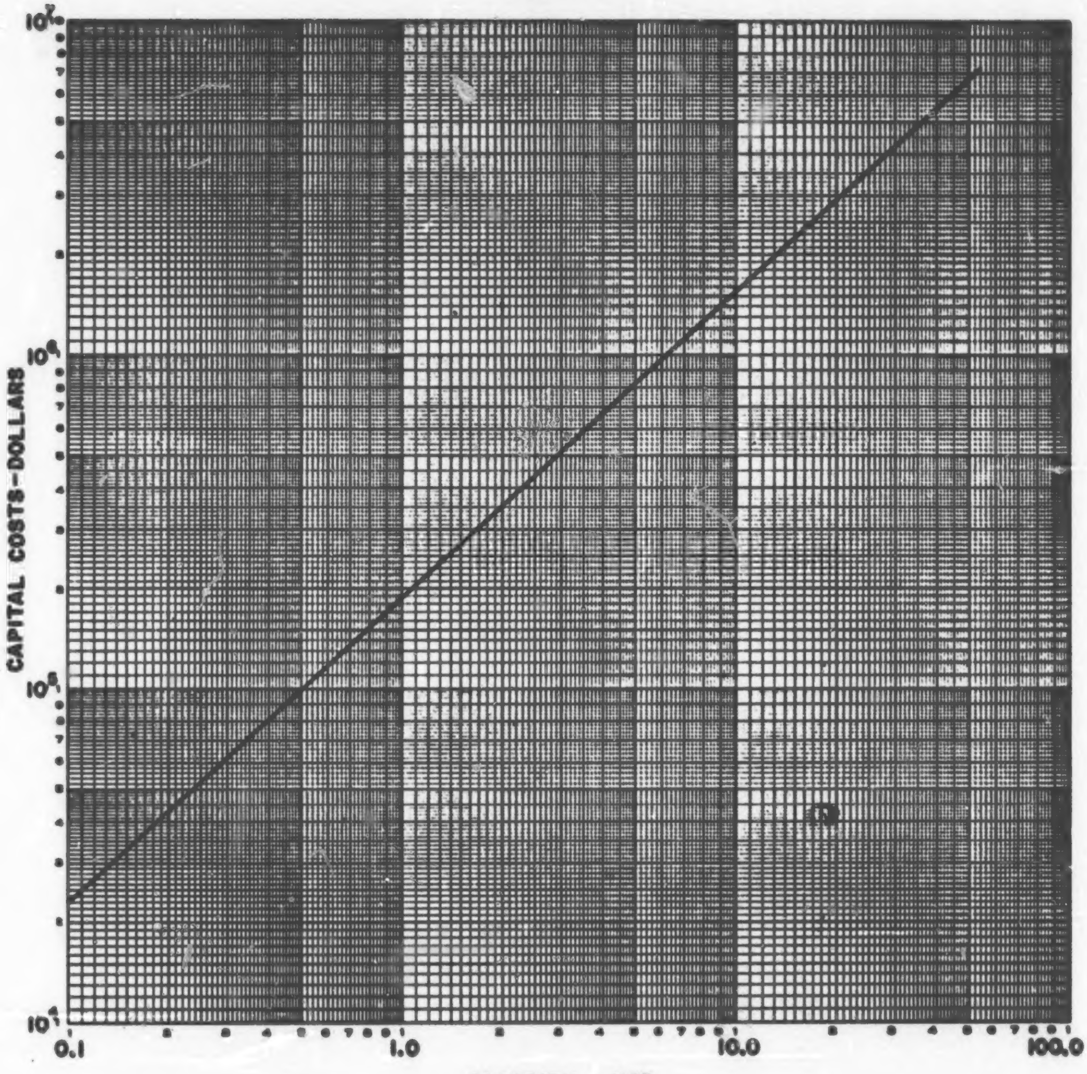
CAPITAL COST RELATIONSHIP
CARBON ADSORPTION

Figure 10-D



CAPITAL COST RELATIONSHIP
ION EXCHANGE

Figure 11-D



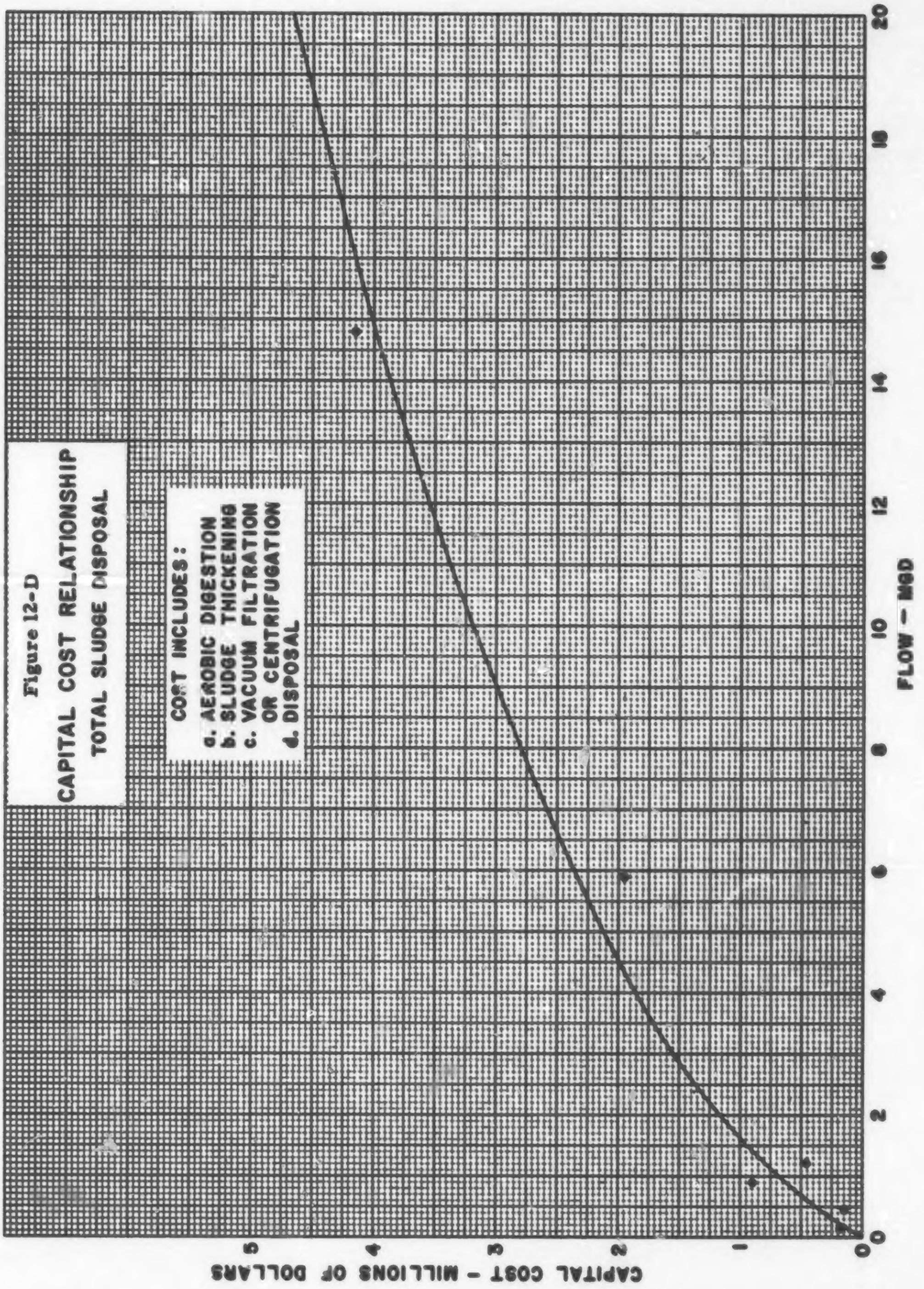


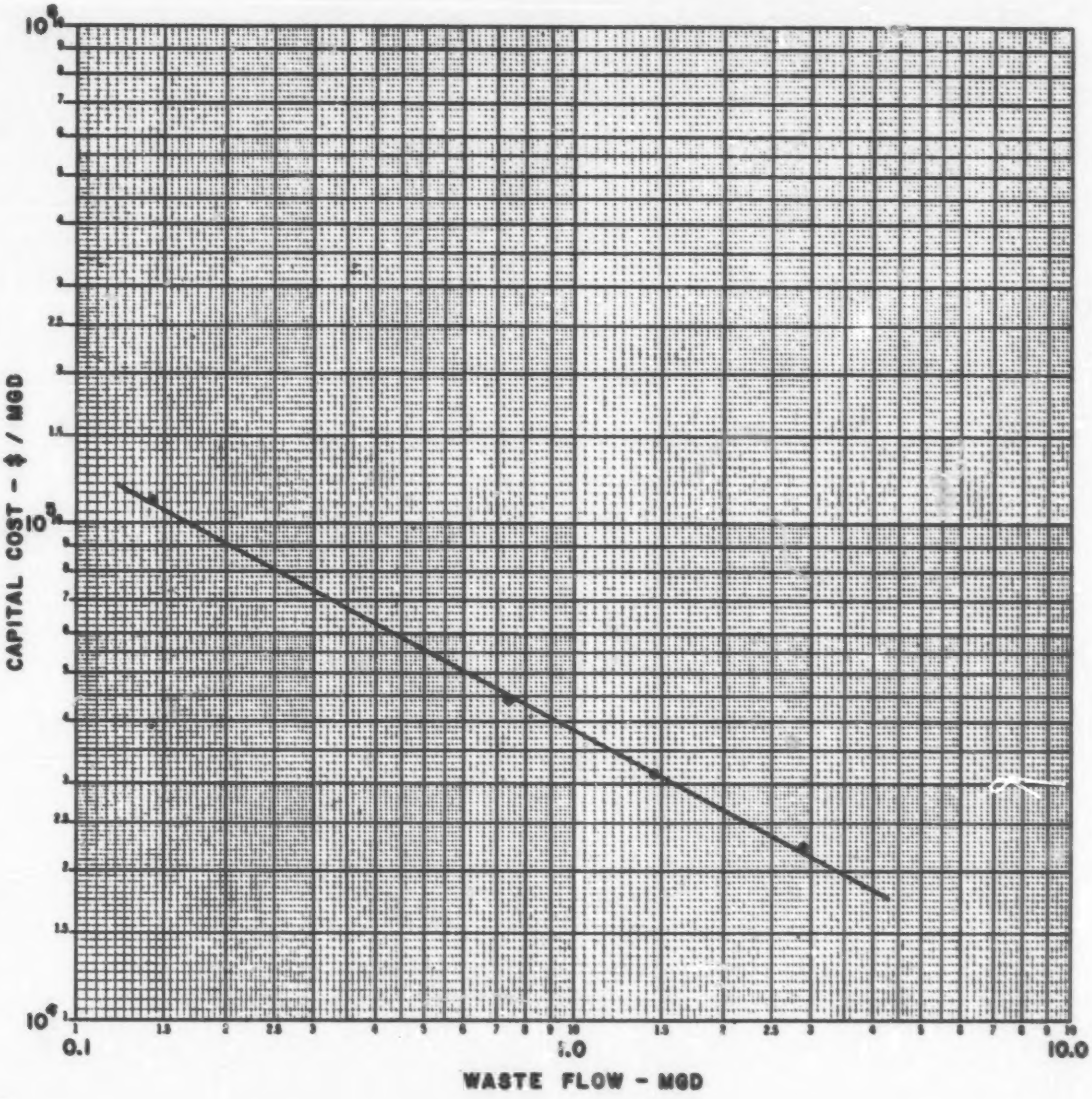
Figure 12-D

CAPITAL COST RELATIONSHIP

TOTAL SLUDGE DISPOSAL

CAPITAL COST RELATIONSHIP
FLOTATION THICKENING

Figure 13-D



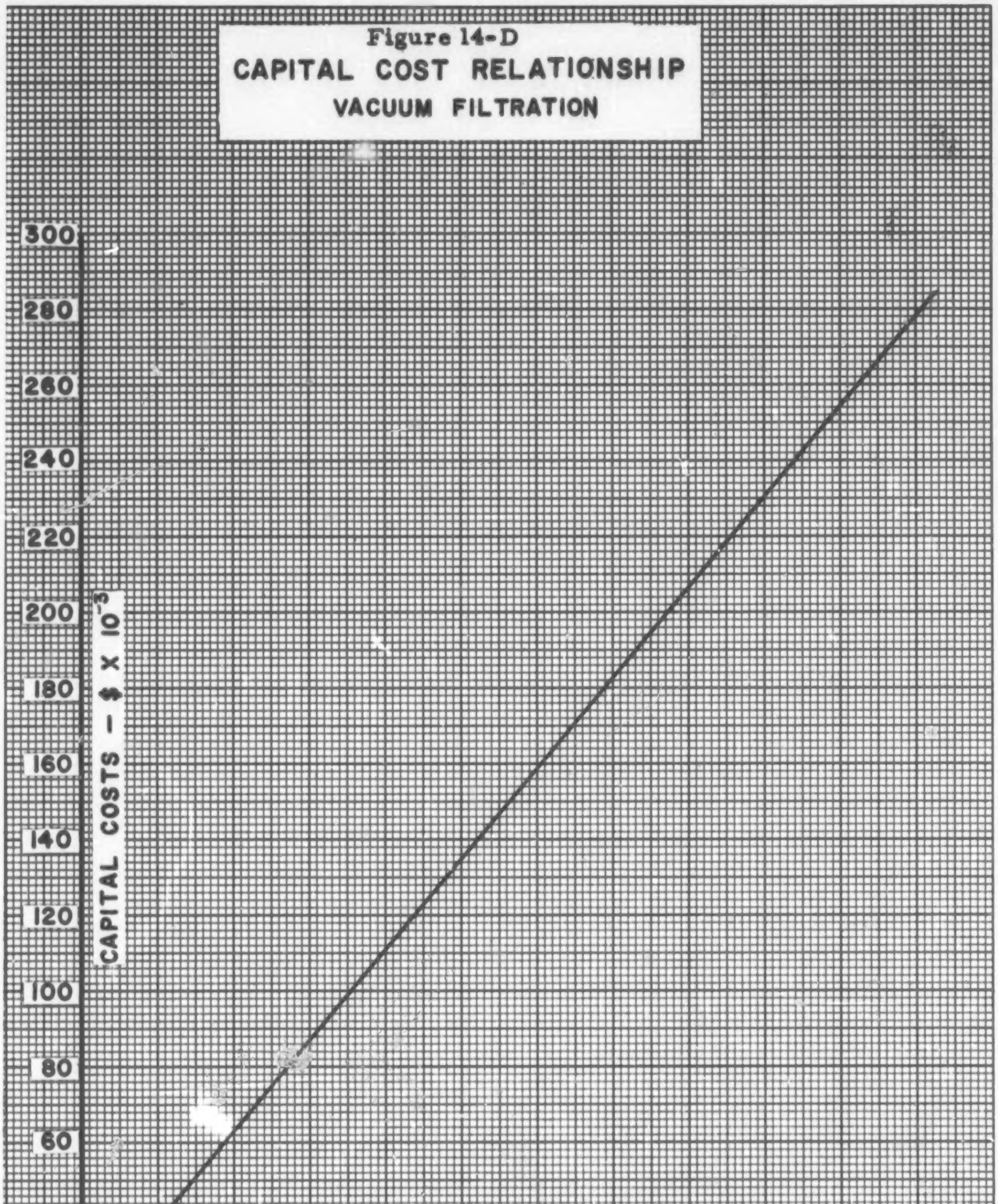


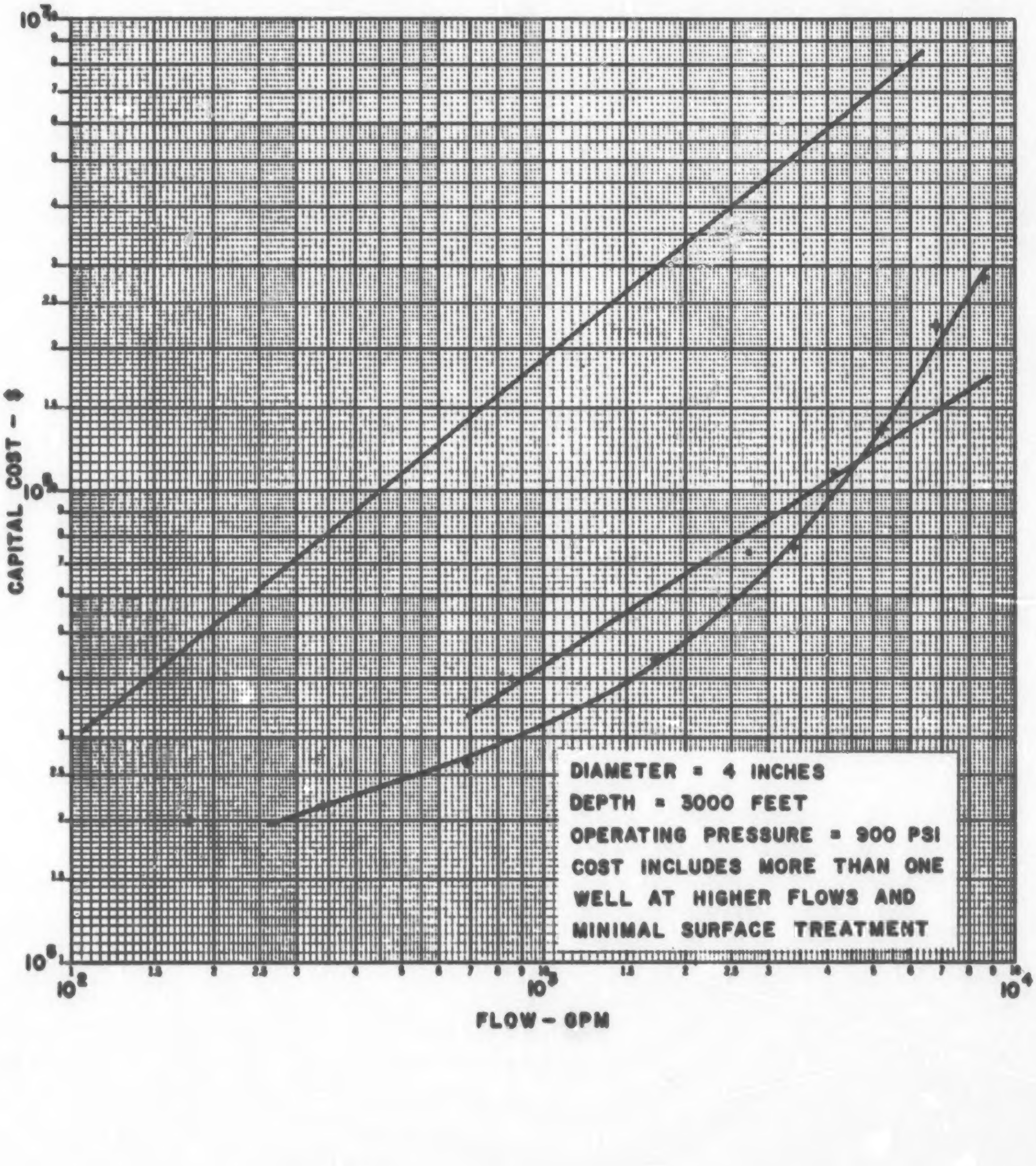
Figure 14-D

CAPITAL COST RELATIONSHIP

VACUUM FILTRATION

CAPITAL COST RELATIONSHIP
DEEP WELL DISPOSAL

Figure 15-D



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